STRATEGIC VALUE ANALYSIS - ECONOMICS OF WIND ENERGY IN CALIFORNIA

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Abstract

With an aggressive Renewable Portfolio Standard (RPS) goal and state *Energy Action Plan*, the California Energy Commission's Public Interest Energy Research (PIER) Renewable Research and Development Program is paving a strategic pathway for the growth and integration of future renewable generation and transmission planning with the Strategic Value Analysis (SVA) effort.

This white paper looks at California's wind resources, its economics, and the benefits they offer society and the state's electric system. The technology base of wind is established, as are current and projected future states of wind economics. Three scenarios are analyzed to further identify the most economic and beneficial resources. A utility-scale analysis, based on proximity to transmission hotspots, was modeled for 2405MW over six California counties. Of that total, 1773MW had positive system benefits without requiring significant transmission upgrades. If transmission upgrades are made, an additional 3256MW would become available by 2017. The second scenario identified between 13MW and 26MW of low-wind speed capacity located near distributed generation hotspots. The third scenario examined significant low-wind speed resources not captured under the utility-scale analysis. A simulated summer peak load of 282MW was injected into the system, yielding a net system benefit of 81MW.

Introduction

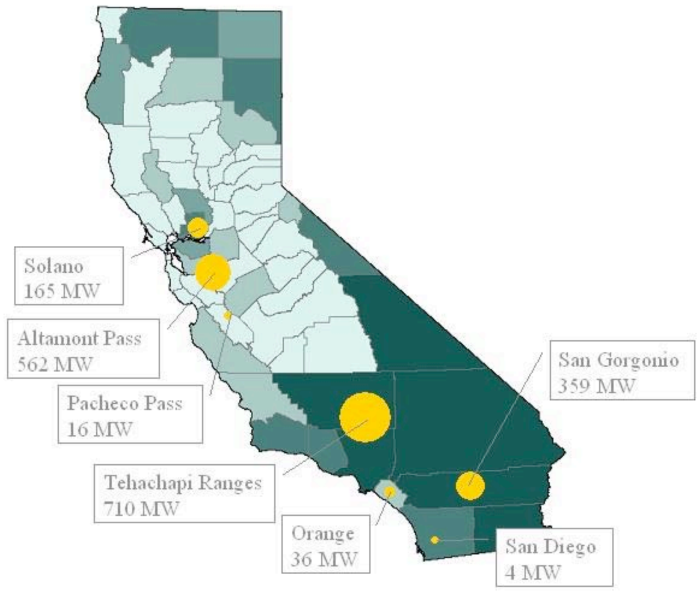
The Strategic Value Analysis (SVA) vision is to provide a “game plan” for addressing and preventing future grid problems. This approach simultaneously considers non-energy benefits for the environment and economy by integrating renewable generation at strategic locations or “hot spots” throughout the state. Comprised of a team of consultants, energy analysts and industrial partners, this multi-phase effort uniquely combines renewable resource assessments, state-of-the-art power flow analysis, related transmission modeling, and assessment of distributed generation potential. SVA solutions and findings directly address the magnitudes and timeframes for transmission and distribution upgrades and establish a set of priorities and upgrade locations.

Though the SVA looks at benefits of all renewable technologies, including wind, geothermal, biomass, solar, and hydro, this white paper summarizes the approach and current findings of the SVA for wind energy. Information developed under the SVA will be incorporated into the Commission’s 2005 *Integrated Energy Policy Report (IEPR)*.

Wind Energy in California

California wind energy generation is comprised of both utility-scale wind generation facilities, and residential-scale wind turbine systems. Existing utility-scale wind power generation facilities are located in five major resource areas in California – Solano, Altamont, San Gorgonio, Tehachapi, and Pacheco (Figure 1). Three of these primary regions (Altamont, Tehachapi and San Gorgonio) account for nearly 95 percent of all commercial wind power generation in California, as well as approximately 11 percent of the world’s wind-generated electricity (Table 1). With average California household use at 6,500 kWh of electricity per year, 3.5 billion kWh of annual electricity generation from wind provides enough electricity to power over 530,000 homes.

Figure 1. Existing wind resource areas in California



Source: California Energy Commission 2003 Wind Performance Reporting System

Table 1. Wind Energy Resources Statistics

Resource Site	Capacity (MW)	Generation (GWh)	Number of Turbines	Location
Altamont	576	1,071	4,788	Northern CA
Solano	165	102	700	Northern CA
Pacheco Pass	16	25	167	Central CA
Tehachapi Ranges	710	1,482	3,444	Southern CA
San Gorgonio Pass	413	893	2,556	Southern CA
State Total	1,880	3,573	11,655	

Source: 2003 Wind Performance Reporting System data.

There is also significant small-scale (< 100 kilowatt) wind capacity installed throughout California for both residential and rural applications. Figure 2 shows two such systems. There was approximately 1 megawatt (MW) of grid-connected small wind capacity installed in California in 2002. Spurred by concern over rising fuel costs and aided by policies like Assembly Bill 1207 (AB1207), requiring local counties to permit small wind systems, the number of turbine systems for residential, rural use and distributed wind generation is expected to rise.

Figure 2. Small Scale <100 kW Wind Systems

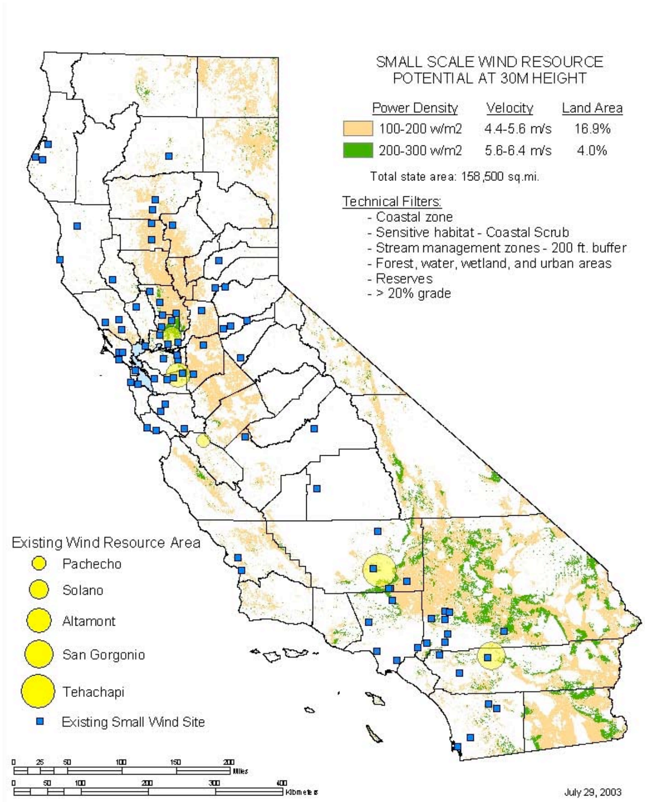
(a) (b)

a) Bergey 10kW wind turbine **b) Southwest Windpower 3.5kW turbine**

Figure 3 shows California wind turbines less than 300 watts per square meter (W/m^2), at 30 meters above ground, with an overlay of current residential and small-scale wind applications throughout the state. It is interesting to note that many small turbines are located outside traditional high-speed wind areas (above Class 5) but are still economically viable because of their proximity to load centers, including:

- Coastal areas
- Central valley areas
- High population corridors
- High electricity demand corridors

Figure 3. Overlay of Existing Small Wind Turbine Locations with Wind Resources in California at 30 M Hub Height



Source: California Energy Commission

Technology Performance Characteristics

The current status of wind technology is divided into two categories by turbine size and summarized in Table 2. The large turbines (greater than 250 kW) are considered large or utility scale. Turbines fewer than 250 kW are typically used for individual homes, farms, or rural electrification. However, the sizes of turbines for these distributed applications are increasing and can be as large as 500 kW.

Table 2. Current Status of Wind Technology for Large and Small Wind Turbines

Technology Characteristics	Less than 250kW	Greater than 250kW
Performance		
Capacity Factor (%)	20-25%	30-40%
Wind Class	> Class 2	Current technology > Class 5; 2017 and beyond > Class 3
Wind Speed (m/s)	> 5 m/s	> 6.5 m/s
Expected Availability (%)	- -	95-99%

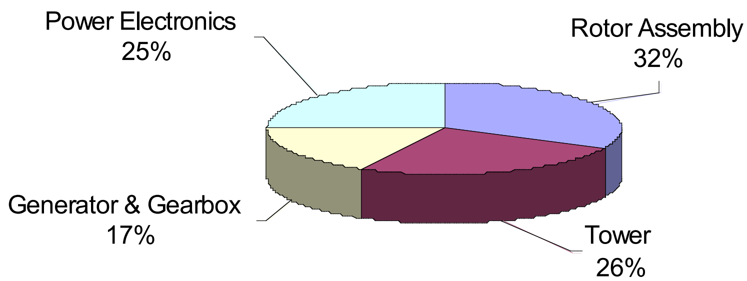
Table 2. Current Status of Wind Technology for Large and Small Wind Turbines (continued)

Technology Characteristics	Less than 250kW	Greater than 250kW
Load Ramp Rate (kW/min)	- -	4,000-11,000
Typical Forced Outage Rate	- -	1-5%
Operation		
Dispatchable	No	No
Load Duty (base, intermediate, peak, intermittent)	Intermittent	Intermittent
Fuel	N/A	N/A
Maintenance		
Cold Start-up Time (minutes)	0	0
Annual Maintenance (hr/yr)		45-55 per kW
Time Before Service (operation hrs)	Variable	6 months
Infrastructure Needs		
Land Use	0.1 to 0.5 acres/kW	30-50 acres/MW
Water Service	N/A	N/A
Fuel Delivery	N/A	N/A
Transmission Access	Low Voltage	High Voltage
Air Emission (compared to typical CCG)		
CO Reduction (lb/MWh)	N/A	N/A
NO_x Reduction (lb/MWh)	N/A	N/A
SO_2	N/A	N/A
Particulate (> 10 micron)	N/A	N/A
Environmental		
Noise (dB SPL)	60 dB	55-65 dB
Electro-magnetic Interference	Possible	Possible
Lighting	No	Yes
Others	Visual	Avian, Visual
Economics		
Installed Capital Cost ($/kW)	$2000-$3,500	$800-$1200
Levelized Cost of Electricity ($/kWh) Without Incentives	- -	0.05-0.07

Source:

A typical wind turbine is comprised of a tower, rotor assembly, power electronics and instrumentations, and generator hardware. Figure 4 shows the cost breakdown for these various components.

Figure 4. Turbine Equipment Cost Breakdown



Source: California Energy Commission

Over the past few years the trend has been to increase the size, efficiency and reliability of wind turbines, making their deployment more cost-effective. As a result, wind power now ranks among the most appealing options for new generation facilities. Wind power has been the fastest-growing energy source for over ten years, and growth in the industry is accelerating with continuing advancements. In 2001 alone, the total wind power capacity installed worldwide grew by about 30 percent to approximately 24,000 MW by year’s end. Average timeframes from project development to generation range from nine months to one year, making wind generation the most rapidly deployable as well as economically viable renewable generation technology.

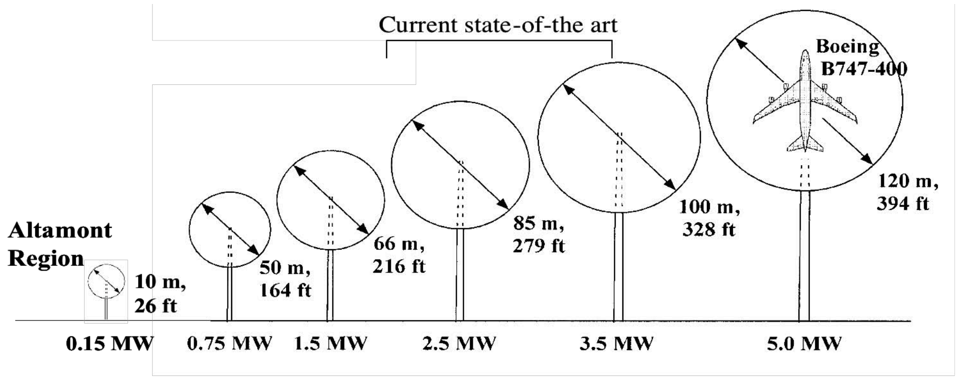
Utility-Scale

Although there are many different configurations of wind turbines, most are classified as either horizontal-axis wind turbines (HAWTs) like old-fashioned windmills, or vertical-axis wind turbines (VAWTs) like the eggbeater-style wind turbines. VAWTs come in two major varieties; aerodynamic lift drives like Darrieus-style wind turbine, named for its French inventor, and the drag-based Savonius-style turbine, which captures wind with its cup-like fins to generate power. Many VAWT designs remain technically promising, but economics and market perception have virtually eliminated them as contenders in today's utility-scale wind energy industry.

Three-bladed, horizontal-axis wind turbines (HAWT) currently dominate the wind industry. HAWT technology has advanced in the past 20 years, with average capacity factors in the mid-30 percent to low-40 percent, compared with the 15-20 percent averages in earlier technologies. The current industry trend is toward both larger and taller turbines (Figure 5). Driven in part by the economies of scale and the offshore turbine market, the cost of energy (COE) for these mammoth systems is nearing an impressive $0.04/kWh, with capacity factors in the range of 38 percent - 40 percent.

Wind system trends in the 1980s focused on machines in the 20–250 kW range. In the mid-1990s, wind systems increased to mid-range (500-kW but less than 1-MW). Current state-of-the-art wind systems are multi-megawatt systems, standing 60 to 80m tall. Rotor diameters on these multi-megawatt systems exceed the scales of commercial transport jets. For offshore applications large, multi-megawatt turbines rated from 3.5 MW to as great as 5 MW are being installed or under development.

Figure 5. Wind turbine size growth trend



Source:

New multi-megawatt turbines include both capital cost and structural load reducing improvements. Turbine component design improvements include:

- Blade-rotor design (materials and aerodynamic loading).
- Blade-tower aerodynamics.
- Power electronics (VAR support, frequency control, ramp rates).
- Gearbox or no gearbox designs (load-splitting, tower weight reduction).
- Generators (asynchronous, synchronous, permanent magnet).

Improvements contribute increases in overall efficiency of the turbine, accounting for as much as a 4 percent improvement in capacity factors. Additionally, optimizing newly-designed turbines for a site and repowering older technologies at existing wind facilities have improved overall capacity factors for various facilities. For example, variable speed turbines have the potential to increase capacity factors by as much as 10 percent over fixed-speed turbines because they provide peak efficiency over a larger percentage of the time, thereby increasing net energy production of the turbine. For large turbines, designing turbines with larger rotors and lower tip speeds is a way to increase the capacity factor and the longevity of individual turbines by lowering rotor revolutions per minute (RPM) and reducing aerodynamic loading. Lower tip speeds also reduce acoustic emissions from these systems, which helps with public acceptance. Other more recent turbine improvements include modifications to better operate with turbulent wind loads, unsteady aerodynamic, stall effects, and complex fatigue loads, making use of technology developments including advanced airfoils tailored for wind turbine applications. Power electronics have been developed to allow variable rotor speed operation, which improves over-all turbine efficiency.

Table 3 summarizes the increase in turbine sizes and energy and annual power output from 1981 to 2000[1], and projected to 2020 for on-shore turbine applications. Both the maximum diameter and tower hub height have increased over this period, enabling the typical annual energy output of a single turbine to increase by a factor of almost 80, with an order-of-magnitude decrease in energy cost. In part due to the economies of scale and technological improvements that allow taller turbines and larger rotors, there is a world-wide trend toward multi-MW turbines. However, besides wind resource constraints, these turbines are approaching structural and material design limits.

Table 3. Increases in On-Shore Wind Turbine Size and Output from 1981 to 2001 and Forecasted from 2005 to 2020

Year	Rotor Diameter (m)	Hub Height (m)	Capacity Rating (kW)	Generation (MWh/yr)	Average Capacity Factor (%)
1981	10	25	25	45	21
1985	17	36	100	220	25
1990	27	40	225	550	28
1996	40	45	550	1480	31
1999	50	65	750	2200	33
2001	62	70	1200	3680	35
Projected					
2005	70	80	1500	4862	37
2010	80	90	2000	7000	40
2015	86	95	2500	9200	42
2020	92	105	3000	11000	43

Source: California Energy Commission

For on-shore applications, multi-MW turbines will have realistic size constraints, potentially fewer than 2.5 or 3 MW. Assuming adequate wind resources at a site, the logistics of transporting 50m-long turbine blades and other components well over the size and height of semi-trucks will prove challenging.

Residential, small-scale

Since the mid 1990s, small-scale turbines have been increasing in size from under 1-kW to current systems approaching 100-kW. They are primarily used by residential homeowners, small farms and rural areas, either on- or off-grid. Several manufacturers produce small-scale turbines.

- **Bergey Windpower** Manufacturer and supplier of Bergey wind turbines from .85kW to 10 kW (50kW machine in development). Based in Norman, Oklahoma.

- Wind Turbine Industries, Corp. Manufacturers of the Jacobs wind turbines. Factory located in Prior Lake, Minnesota.
- Southwest Windpower Manufacturers of Windseeker and AIR turbines. Based in Flagstaff, Arizona.
- World Power Technologies Manufacturer of Whisper wind turbines (600 watt - 3kW). Based in Duluth, Minnesota.
- Atlantic Orient 50 and 12 kW wind turbine manufacturer. Offices in Vermont and Nova Scotia.
- Nordex wind turbine manufacturers (Denmark).

Compared with utility-scale wind turbines, small systems have different aerodynamic control mechanisms in addition to less efficient blade profiles. Small turbines are reaching the limit of their furling control. Many technology improvements being made on large-scale systems (noted above) are trickling down to these smaller systems, especially in the area of rotor-blade design. As large turbines continue to grow in size, small turbine manufacturers will find a niche market offering small and mid-range turbines for low wind speed applications, especially in the RPS-driven market.

Strategic Value Analysis Methodology and Approach

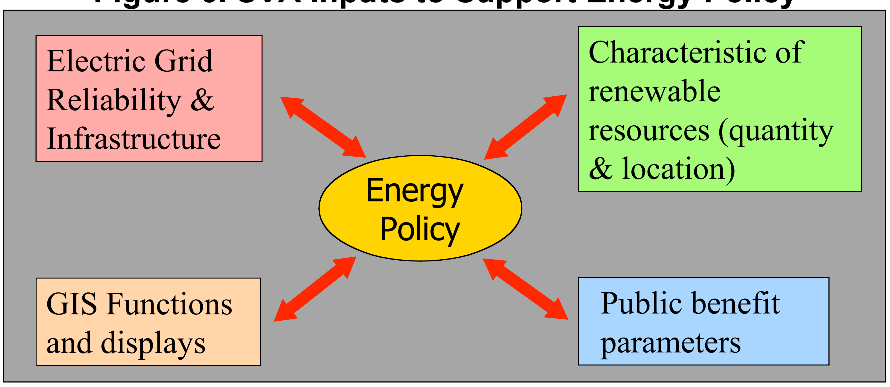
The Energy Commission has developed a methodology under the Strategic Value Analysis (SVA) that prioritizes, identifies, and optimizes transmission infrastructure and new technology R&D planning for renewable resources. As shown in Figure 6, the SVA methodology uniquely combines resource assessments, and power flow analysis with economic drivers/benefits in order to prioritize renewable development that supports RPS policy. Any renewable development plan would be incomplete without an integrated approach that considers both infrastructure planning needed by 2017 and targeted technology improvements.

The goal of the SVA effort is to develop a strategic plan and “roadmap” for integrating renewables into California’s grid to meet RPS goals. The approach includes:

- Assessing renewable resource potential and technologies to meet RPS goals.
- Identifying key focus areas for development for each renewable technology.
- Evaluating economics and timeframes for development for maximum public benefits (energy and non-energy).

- Evaluating points of high strategic value to the grid or "hotspots".
- Considering solutions with significant environmental, economic and other non-energy benefits to the state.
- Providing solutions that defer transmission upgrades and help prioritize transmission needs.
- Prioritizing renewable implementation and transmission infrastructure needs by resource.
- Developing a portfolio mix of renewable resources needed to meet RPS goals.

Figure 6. SVA Inputs to Support Energy Policy



SVA scenario-based analysis provides statewide development priorities for various regions with the focus on identifying and developing the "lowest hanging fruit," defined as developing the most economic and beneficial renewable resources first.

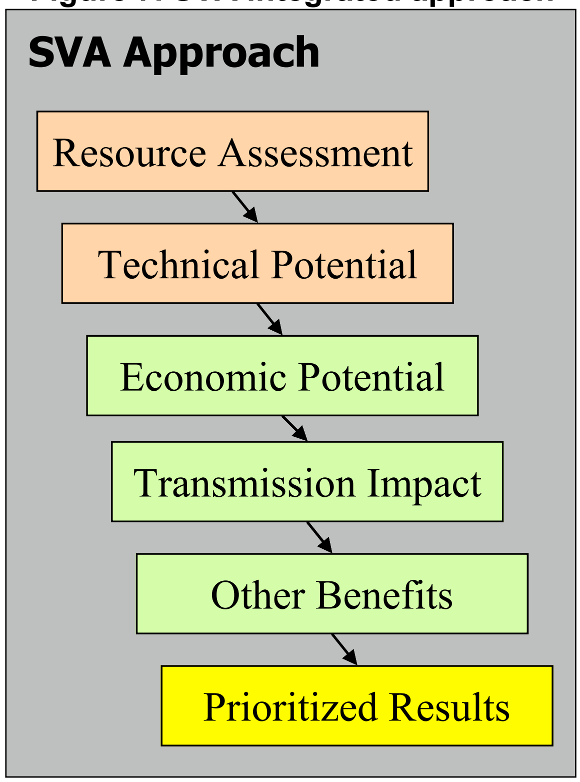
Steps of the SVA are shown in Figure 7. Beginning with a resource assessment, the total gross resource potential was quantified. This total gross potential was systematically filtered by a set of technical filters to determine its technical potential. SVA technical results for wind were presented at an Energy Commission Public Workshop on May 9th, 2005, and summarized in the workshop white paper (CEC500-2005-070D). Results show that California has significant instate wind resources and, by including low speed wind resource areas, the total technical potential minus existing development is near 98,000MW (Table 4).

Table 4. California Technical Wind Power and Annual Energy Production Potential

	High Wind Speed >500W/m²			Low Wind Speed 300W/m² - 500W/m²			Total	
Height m	Land Area Percent	Capacity MW	AEP GWh	Land Area Percent	Capacity MW	AEP GWh	Capacity MW	AEP GWh
30	0.2	4775	15478	1.2	30897	100144	35673	115623
50	0.4	9586	31070	2.2	56196	182144	65782	213214
70	0.6	14346	46500	3.3	85598	277441	99945	323940
100	0.8	21339	69164	4.9	126558	410199	147897	479362

(Source: California Energy Commission)

Figure 7. SVA integrated approach



Source: California Energy Commission

Economic filters, as discussed in the next section, further reduce the technical resource potential to economic potential. Next, economic potential is evaluated for its most significant impact on alleviating congestion on the electrical grid, as well as for other economic drivers/benefits. The single resource study and transmission impact (based on a power flow model) are then integrated with other renewable resources available instate, relative to the region of study, to arrive at the final integrated statewide prioritized solution that includes:

- Capacity in MW by generator type.
- Focus areas by location.

- Transmission upgrades needed.
- Transmission implementation cost projections (does not include rights of way or land use costs).
- Levelized cost of energy (LCOE) projections for 2005, 2010, and 2017.

Tools/models used in the SVA include:

Technical	• Renewable resource assessments • Transmission power flow simulations • Utility transmission pathway database and planning models
Economic	• Cost model
Visual	• GIS data layers • GIS analysis

Economic Analysis and Prioritization

To evaluate the economic potential of developing wind resources for the state, both geographic and temporal perspectives were used. Geographically, potential sites were identified based on transmission impact and cost effectiveness (compared with a baseline reference). Transmission analysis was conducted by Davis Power Consultants (DPC), using the PowerWorld model and focusing on improving system reliability. Factors included:

- Proximity of resource to transmission interconnection points.
- Beneficial impact on the transmission grid.
- Level of upgrades needed for existing transmission lines and substations.
- Need to invest in new transmission infrastructure.

Site development is prioritized based on wind energy costs as compared with some market references including forecasted wholesale electricity price, market price referents (MPRs), and combined-cycle generation costs.

Geographic Evaluation of Wind Sites

Based on high-resolution maps, a summary of filtered technical potential for wind generation is provided by county. High wind speed (greater than Class 5) and low wind speed resources (Class 3 and 4 winds) are separate. By 2017, low speed wind turbine technologies are assumed to be available. For 2010 and 2017 analysis years, the capacity from high wind turbine technologies is projected to be 7,056 MW. There are 19 counties expected to have wind potential ranging from 1 MW to 2,038 MW. The priority for the economic analysis is for counties with the most significant potential.

In the economic analysis, the approach focused on areas with local and regional generation benefits. The local analysis includes evaluation of counties with large concentrations of wind power potential that are close to transmission congestion areas or "hot spots". These "hot spots" or problem areas were determined by running a contingency analysis which looked at over 5,000 transmission lines, transformers and power plants in the state. Davis Power Consultants (DPC) performed the transmission analysis using power flow simulations, and developed a methodology to prioritize locations for new power plants which would alleviate congestion and provide positive benefit to the grid. DPC created factors to prioritize locations and compare transmission benefits. A factor called the Weighted Transmission Loading Relief Factor (WTLR) indicates the effectiveness of installing new generation at a bus. For example, a bus with a WTLR of two means that for every 1 MW of installed generation there will be a corresponding 2 MW reduction in the contingency overload. The Aggregated Megawatt Contingency Overload (AMWCO) indicates the overall reduction that the new generator has on the reliability of the entire system. The AMWCO is not to be confused with the amount of generation or transmission that needs to be added to the system. A negative AMWCO indicates a negative Impact Ratio, which in turn indicates that addition of a new generator at a site would provide a benefit to overall reliability of the grid.

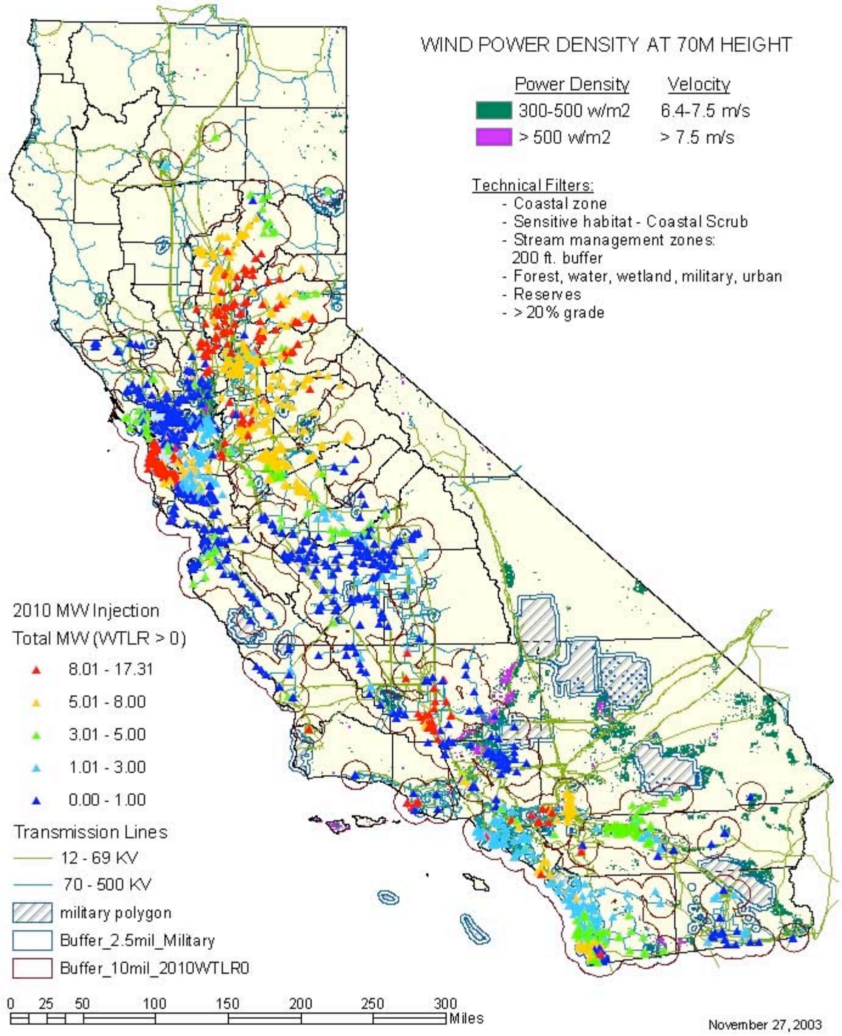
A 10-mile radius buffer zone was selected around local "hot spots" for analysis. The regional analysis would identify resources outside the initial "hotspot" focus areas and anticipate significant transmission upgrades. Based on the transmission analysis, resource sites could then be prioritized by counties, based on local and regional transmission development costs.

The steps for the analysis are listed below.

1. Counties with high wind potential and locations within 10 miles of transmission "hot spots" were analyzed. The analysis first determined the magnitude of wind power that could be added to the existing transmission system without upgrades. Location benefit of the wind resource was calculated as an impact ratio. A negative impact ratio shows significant benefit on the transmission grid if the resources are added, while a positive impact ratio would degrade the system.

2. Once the wind power magnitude and impact ratio have been determined, the analysis determines required transmission and associated costs to deliver the remaining high wind speed power to the system. The location benefit of the wind resource is again calculated as an impact ratio.
3. Low wind speed power is expected to be available by 2017. These resources were evaluated for the 2017 time period. The studies quantify the transmission expansion that could be required if the full low wind potential were developed.
4. Wind generating potential from Los Angeles and Kern counties was also considered. These sites are remote from "hot spots" but contain more than 3,950 MW of wind potential. These sites were studied together and evaluated as *regional resources*. Given that major and extensive transmission will be required to transmit this power, development is assumed to be fully available by 2017. There could be some power provided in the 2010 time frame, depending upon the transmission development approved, permitted, and constructed.

Figure 8. Wind Resource Areas Relative to Key Substations with Buffer Zones



Wind resource data were evaluated geographically for the most significant impact on alleviating congestion on the electrical grid. The further a resource area is from a substation, the lower the economic priority of development due to grid upgrade and connection costs. The technical wind potential derived from the wind resource maps for each county was filtered by proximity to key substations and transmission lines, as shown in Figure 8. An initial 10-mile buffer zone was placed around key substations, assuming resources would be available to develop at least 10 miles of transmission or upgrades. In addition, military bases were identified to mitigate encroachment on restricted and military buffer zones. Table 5 summarizes the availability of wind resources within 10 miles of key substations for years 2005, 2007, 2010, and 2017.

Table 5. California Economic Wind Potential and Energy Production Potential

(Filtered, 2005 WTLR > 0, 10mi buffer)

	High Wind Speed			Low Wind Speed			Total	
Height m	Land Area Percent	Capacity MW	AEP GWh	Land Area Percent	Capacity MW	AEP GWh	Capacity MW	AEP GWh
30	0.001	2255	7309	0.004	9986	32367	12241	39676
50	0.002	4229	13707	0.006	14859	48160	19088	61867
70	0.002	6071	19676	0.008	19268	62452	25339	82128
100	0.003	8102	26259	0.010	25647	83126	33748	109384

(Filtered, 2007 WTLR > 0, 10mi buffer)

	High Wind Speed			Low Wind Speed			Total	
Height m	Land Area Percent	Capacity MW	AEP GWh	Land Area Percent	Capacity MW	AEP GWh	Capacity MW	AEP GWh
30	0.001	2451	7945	0.005	11783	38192	14235	46137
50	0.002	4809	15589	0.007	16792	54426	21601	70014
70	0.003	7022	22759	0.008	20904	67754	27926	90513
100	0.004	9326	30227	0.010	26915	87236	36241	117463

(Filtered, 2010 WTLR > 0, 10mi buffer)

	High Wind Speed			Low Wind Speed			Total	
Height m	Land Area Percent	Capacity MW	AEP GWh	Land Area Percent	Capacity MW	AEP GWh	Capacity MW	AEP GWh
30	0.001	2458	7968	0.005	11992	38869	14451	46837
50	0.002	4820	15622	0.007	17613	57088	22433	72709
70	0.003	7056	22870	0.009	23197	75187	30253	98057
100	0.004	9397	30458	0.012	30409	98563	39807	129021

(Filtered, 2017 WTLR > 0, 10mi buffer)

	High Wind Speed			Low Wind Speed			Total	
Height m	Land Area Percent	Capacity MW	AEP GWh	Land Area Percent	Capacity MW	AEP GWh	Capacity MW	AEP GWh
30	0.001	2464	7987.8	0.005	11929	38664	14393	46651
50	0.002	4831	15658	0.007	17135	55538	21966	71196
70	0.003	7055	22866	0.008	21538	69809	28593	92674
100	0.004	9392	30441	0.011	28222	91474	37614	121914

From 19 potential counties with significant high wind speed resources, six counties were selected for the detailed economic *local resources* wind studies and transmission impact studies. These sites are attractive economically since they provide potential alleviation of transmission hotspots and utilize existing transmission infrastructure with some or no transmission upgrades.

Economic Evaluation of Wind Sites

To predict the timing for developing resources in a region, an economic cost model was used to calculate the levelized cost of electricity (LCOE), in both constant dollars and current dollars for wind projected to be in service from 2005 to 2017. Details of the economic cost model are provided in the Appendix.

Resulting LCOEs for wind in current dollars were compared in Figure 9 with various energy cost baselines including:

- Energy Commission 2003 forecasted electricity wholesale prices.
- California Public Utilities Commission (CPUC) forecasted electricity wholesale prices.
- Current combined-cycle generation facility costs.

Figure 10 shows the comparison of LCOE for wind with a combined-cycle facility in constant (2004) dollars. Wholesale price predictions are based on natural gas prices. The Energy Commission forecasts can be found in the 2003 Electricity Report (www.energy.ca.gov). CPUC prices are based on an analysis completed by Energy and Environment Economics, Inc. (E3), and are consistent with methodology and inputs adopted for the CPUC Avoided Cost proceeding in Rulemaking 04-04-025, April 7, 2005. Details of E3's methodology and input assumptions can be found on their website:(www.ethree.com/cpuc_avoidedcosts.html).

As shown in Figures 9 and 10, when the LCOE for wind is below or intersects the selected cost baseline (i.e. Energy Commission forecasted wholesale price), the value of wind-generated electricity is as economically cost competitive as conventional generation. The degree to which LCOE is below the selected cost baseline determines the availability of funds to invest in additional transmission upgrades. This in turn determines:

- How far the wind facility can be located from a key substation.
- The timing of developing capacity at the site.

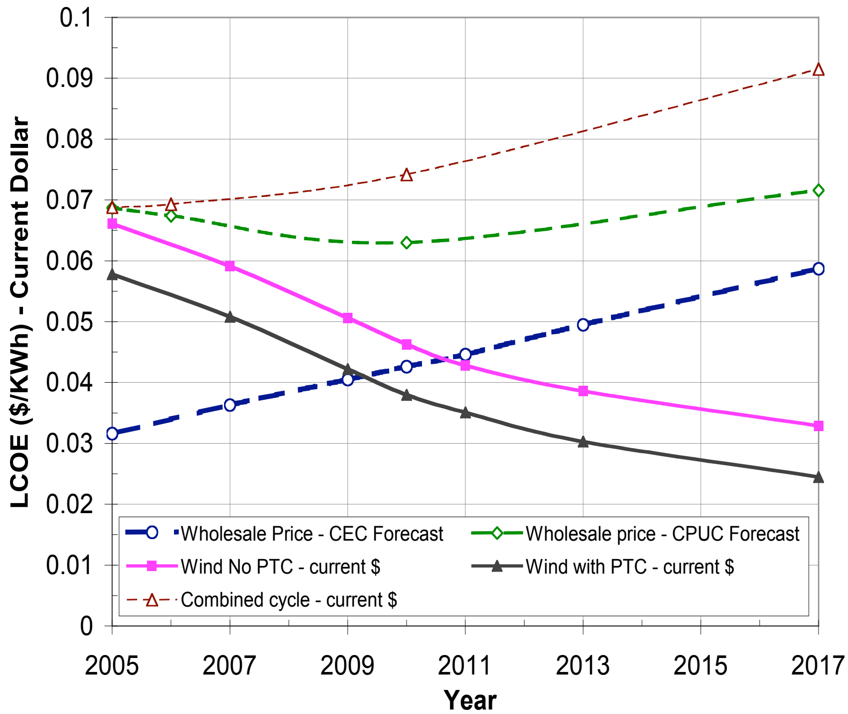
As shown in Figure 9 and summarized in Table 6, compared with the CPUC's wholesale price forecast and the fuel cost of combined-cycle systems, listed at \$0.07/kWh, wind generated electricity is cost competitive starting from 2005 at a LCOE with the federal tax credit (PTC) of \$0.0578/kWh and \$0.0661/kWh, without PTC. The \$0.01/kWh difference between the cost baseline and wind LCOE gives an indicator on the available resources for investing in transmission and other integration costs.

Compared with the more conservative 2003 Energy Commission forecasted wholesale price (\$0.0405/kWh), wind generated electricity is cost competitive by 2009 at a projected LCOE with PTC of \$0.041/kWh (in current dollars) or LCOE of \$0.034/kWh (in constant dollars, Figure 10). Beyond 2009, LCOE with PTC for wind falls below the Commission's forecasted wholesale price curve, making it economically cost competitive to meet 2010 accelerated renewable goals. Without the PTC, the timeframe pushes out to 2010 under the same analysis scenario.

Table 6. Results of Current Dollar Comparison of Wind LCOE to Various Cost Baselines

Current $ Results					
Year	Wholesale Price CEC Forecast ($/kWh)	Wholesale price CPUC forecast ($/kWh)	Wind LCOE no PTC ($/kWh)	Wind LCOE with PTC ($/kWh)	Combined Cycle ($/kWh)
2005	0.0316	0.0690	0.0661	0.0578	0.0690
2006	--	0.0674	--	--	0.0693
2007	0.0363	--	0.0591	0.0508	--
2009	0.0405	--	0.0506	0.0422	--
2010	0.0426	0.0630	0.0463	0.0380	0.0742
2011	0.0446	--	0.0428	0.0351	--
2013	0.0495	--	0.0386	0.0303	--
2017	0.0587	0.0716	0.0329	0.0245	0.0915

Figure 9. Comparison of wind LCOE in current dollars to various baseline forecasted electricity prices.



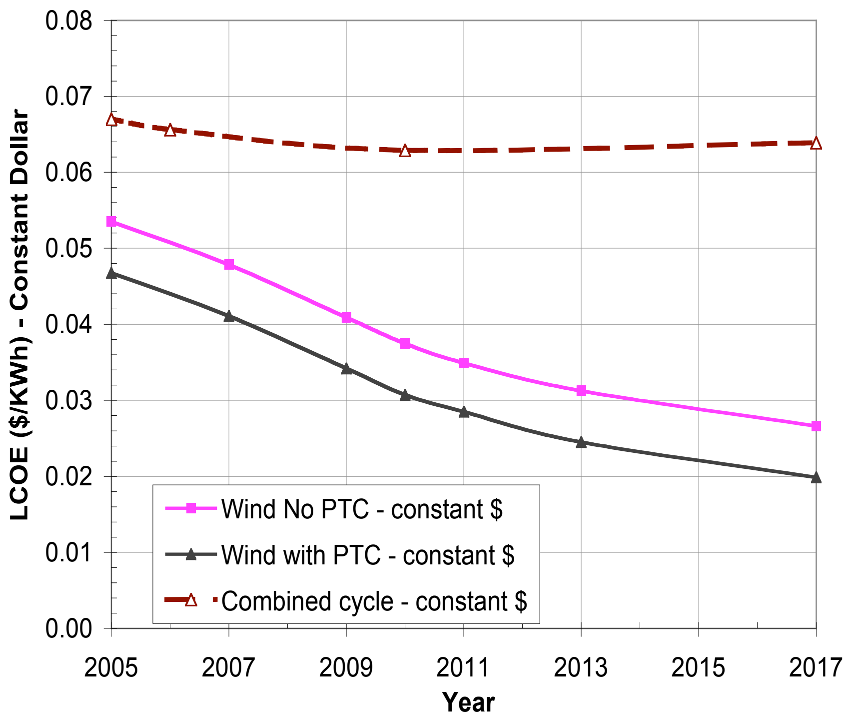
Source: California Energy Commission and CPUC

Table 7 and Figure 10 provide a constant dollar perspective on LCOE as compared with typical combined-cycle facilities. Again the trend identified wind energy as $0.01/kWh to $0.035/kWh more cost effective.

Table 7. Results of Constant Dollar Comparison of Wind LCOE with a Typical Combined-Cycle Facility

2004 Constant $ Results			
Year	**Combined Cycle ($/kWh)**	**Wind LCOE no PTC ($/kWh)**	**Wind LCOE with PTC ($/kWh)**
2005	0.0670	0.0535	0.0468
2006	0.0656	--	--
2007	--	0.0478	0.0411
2009	--	0.0409	0.0342
2010	0.0629	0.0375	0.0307
2011	--	0.0349	0.0285
2013	--	0.0312	0.0245
2017	0.0639	0.0266	0.0199

Figure 10. Comparison of Wind LCOE in Constant Dollars to a Typical Combined-Cycle Facility



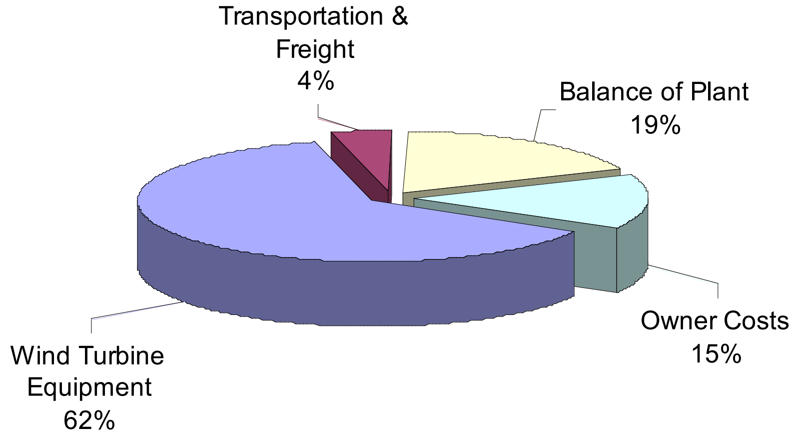
Source: California Energy Commission

Cost Model Assumptions

The cost model assumes the following:

- LCOE assumes a project/owner developer perspective.
- Net plant capacity is 50MW.
- Cost for in-service capital cost in 2005 is $1,020/kW. Typical capital costs include total wind turbine equipment, transportation and freight, balance of plant, and other owner costs. Wind turbine equipment accounts for approximately 60 percent of all capital costs (Figure 11).

Figure 11. Cost Breakdown (in Percent of LCOE)



Source: California Energy Commission

Table 8 shows estimated capital costs, operation and maintenance (O&M) costs and capacity factors for the years analyzed. See Appendix A for 2005 base case (high speed wind resource, utility-scale) calculations and results.

Table 8. Cost Analysis Input Parameters [3]

Technology	**High Speed Wind Resource**			
Year	**2005**	**2007**	**2010**	**2017**
Installed Capital Costs ($/kW)				
Total Wind Turbine Equipment	639	575	479	415
Transportation & Freight	43	38	32	28
Balance of Plant	190	171	143	124
Owner Costs	148	134	111	96
Total Capital Costs	1020	918	765	663
Expenses including Operation & Maintenance ($/kWh)				
Fuel Cost ($/t)	0	0	0	0
Labor Cost ($/kWh)	0.01	0.009	0.006	0.003
Maintenance Cost ($/kWh)	0.007	0.006	0.005	0.003
Insurance/Property Tax ($/kWh)	0.002	0.002	0.002	0.002
Utilities ($/kWh)	0.001	0.001	0.001	0.001
Management/Administration ($/kWh)	0.004	0.004	0.003	0.001
Total Expenses ($/kWh)	0.024	0.022	0.017	0.01
Capacity Factor (%)	**37**	**38**	**40**	**43**

Source: California Energy Commission

Table 9 shows other input parameters used in the economic model. See Appendix A for explanation of details (MACRS – 5 yr property, debt-to-equity ratio, and others).

Table 9. Economic Model - Other Input Parameters

TAXES

Federal Tax Rate (%)	34.00
State Tax Rate (%)	6.65
Production Tax credit ($/kWh)	0.000
Combined Tax Rate (%)	**38.39**

INCOME Other Than Energy

Capacity Payment ($/kW-y)	**0**
Interest Rate on Debt Reserve (%)	**7.00**

ESCALATION/INFLATION

General Inflation (%)	**2.80**
Escalation--Other (%)	**2.80**

FINANCE

Debt ratio (%)	**67.00**
Equity ratio (%)	33.00

Interest Rate on Debt (%)	**8.40**
Life of Loan (y)	**20**
Cost of equity (%)	**16.00**
Cost of Money (%)	10.91
Total Cost of Plant ($)	50,983,991
Total Equity Cost ($)	16,824,717
Total Debt Cost ($)	34,159,274
Capital Recovery Factor (Equity)	0.1687
Capital Recovery Factor (Debt)	0.1049
Annual Equity Recovery ($/y)	2,837,775
Annual Debt Payment ($/y)	3,583,397
Debt Reserve ($)	3,583,397
Annual Debt Reserve Interest ($/y)	250,838
Annual Capacity Payment ($/y)	0
Loan Origination Fee (% of total cost of plant)	**2**

ACRS DEPRECIATION

Year 1	**0.2000**
Year 2	**0.3200**
Year 3	**0.1920**
Year 4	**0.1152**
Year 5	**0.1152**
Year 6	**0.0576**
Total	1.0000
Additional 30% first year depreciation (%)	**30**
Annual Production (kWh)	162,060,000
Annual Hours	3,241

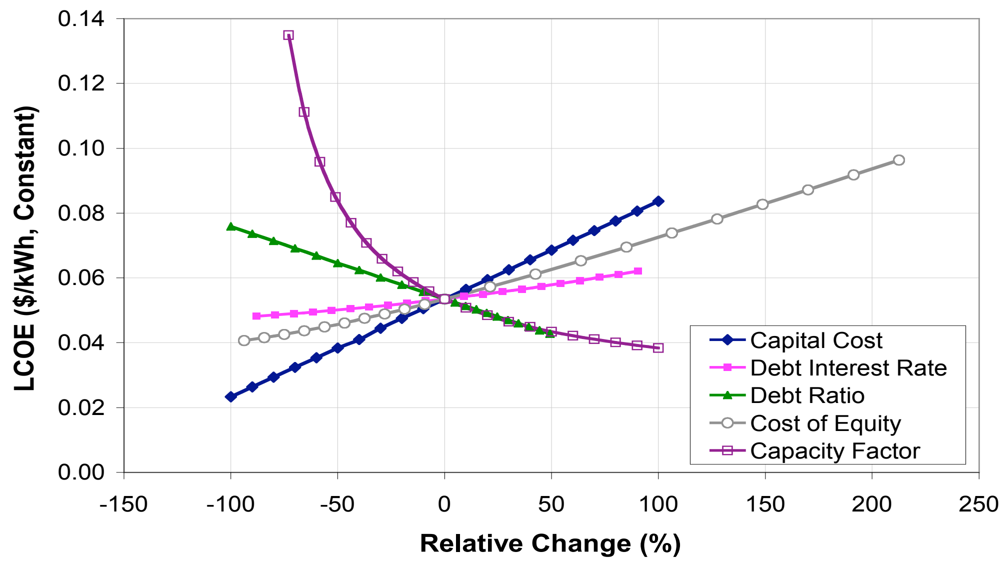
Source: California Energy Commission

Figure 12 illustrates the sensitivity of LCOE to economic parameters including capital cost, debt ratio, capacity factor (CF) and interest rate. A comparison is provided to assess the impact of economic assumptions on model output and provide perspective on how these parameters influence the result (in terms of relative change).

Based on the analysis, capacity factor assumptions most significantly affect the LCOE. A 30 percent decrease in CF (10 percent) increases the LCOE from $0.0535 base case to $0.0659. Capital cost estimates also have notable impact on LCOE. A 30 percent increase in capital costs ($305/kW) results in about $0.01 increase in LCOE.

Capacity factor targets and capital cost estimates must be reassessed annually to ensure the most accurate accounting of LCOE.

Figure 12. Sensitivity of LCOE (2004 Constant $/Kwh) for High Speed Wind Resource Using 2005 Base Case Assumptions



Source: California Energy Commission

Analysis Results

Both utility-scale and smaller-scale (residential to DG) applications for wind were included to determine the total economic potential for wind. Three scenarios were created to assess the transmission impact and economic valuation. Results in MW installed values, development locations and transmission impact will be summarized. Details of the transmission analysis will be provided in a forthcoming Energy Commission consultant report by DPC.

Scenarios studied include:

1) Utility-scale analysis – Scenario 1: Based on transmission benefit and proximity to “hotspots” as described earlier, high wind speed (HWS) and low wind speed (LWS) resource areas were selected using 70 meter wind density data. Land area with adequate wind potential that are within a 10-mile radius buffer zone around substations (with WTLRs > 2) were binned based by wind power density for all counties to determine total MW of available wind. A transmission power flow model simulation determined that MWs could be injected at the substation and the impact ratio (benefit ratio) could be ranked at the sites.

2) LWS hotspot analysis – Scenario 2: Identify hotspots on DG level (fewer than 200kV) transmission (2017 WTLR impact) and locate all wind resources within a 10-mile buffer zone of the hotspots, by county. Power flow models will then be used to determine the types of performance

characteristics of distributed generation systems needed to help resolve "hot spot" conditions.

3) LWS targeted analysis – Scenario 3: Offload of transmission with LWS regional resources. This approach re-evaluated sites with significant LWS potential that had not been studied under the analysis described in Scenario 1, above. Using the data at 30m height, 2010 WTLR transmission impact results, within a 10-mile buffer zone of substations, and including LWS >200W/m^2 but < 500W/m^2, a listing of MW by counties was generated. This approach provided sites not in the original transmission hotspots (WTLR > 2) identified with the HWS and LWS 70m potentials, but with potential to offload transmission lines if these areas were included at the distribution (DG) level.

Utility-scale Analysis

Overlaying transmission "hotspots" (>200kV) with available 70m wind potential identified 19 potential counties with significant high wind speed resources. From these 19 counties 6 counties (Table 10) were selected for the detailed economic *local resources* wind studies. These sites are economically attractive since they can alleviate potential transmission congestion at hotspots and be developed utilizing existing transmission infrastructure with little or no transmission upgrades within the 2010 timeframe.

Table 10. Six Counties Selected for Detailed Economic Local Resources and Transmission Impact Studies

County	High Wind Speed (MW)	Low Wind Speed (MW)
Alameda	132	490
Imperial	82	1,099
Riverside	1,416	3,785
San Bernardino	280	1,621
San Diego	756	2,709
Solano	275	4,345
Total	**2,941**	**14,049**

Source: California Energy Commission

Two additional counties were selected for economic *regional resources* wind studies based on availability of significant wind resources (Table 11). Their remote locations and distance from transmission hotspots require significant transmission investment and upgrades to accommodate the amount of MW potential. Installation of these facilities is therefore not anticipated until 2017 and beyond.

Table 11. Counties Selected for Regional Resource Wind Studies (Tehachapi Area)

County	High Wind Speed (MW)	Low Wind Speed (MW)
Los Angeles	1,571	2,724
Kern	1,467	2,255
Total	**3,038**	**4,979**

Source: California Energy Commission

Results of the power flow analysis and transmission infrastructure needed to integrate the economic wind potential are summarized in Tables 12 and 13. For the transmission power flow analysis, the fully installed wind capacity was adjusted based on summer peak conditions. For purposes of the transmission analysis, an Effective Transmission Wind Capacity (ETWC) was set at 60 percent of installed wind capacity.

In 2010, transmission analysis shows that several sites could provide marginal to good system benefits if the sites were developed. The negative Impact Ratio reflects improved system reliability. These sites also have existing transmission infrastructure so there are no additional transmission upgrade costs.

Table 12. 2010 SVA Wind Results

Site	MW Installed	ETWC (MW)	Impact Ratio	Rating
Alameda	132	79	-0.125	Marginal
Solano	275	165	-0.67	Good
Riverside	1416	850	-1.4	Good
LA/Kern	500	300	0.433	Poor
Imperial	82	50	--	--
San Diego	50	30	1.13	Poor

Table 13 summarizes the 2017 transmission analysis results. Development of these sites would require significant transmission upgrades and new infrastructure. Estimates are based on local utility providers' transmission planning estimates.

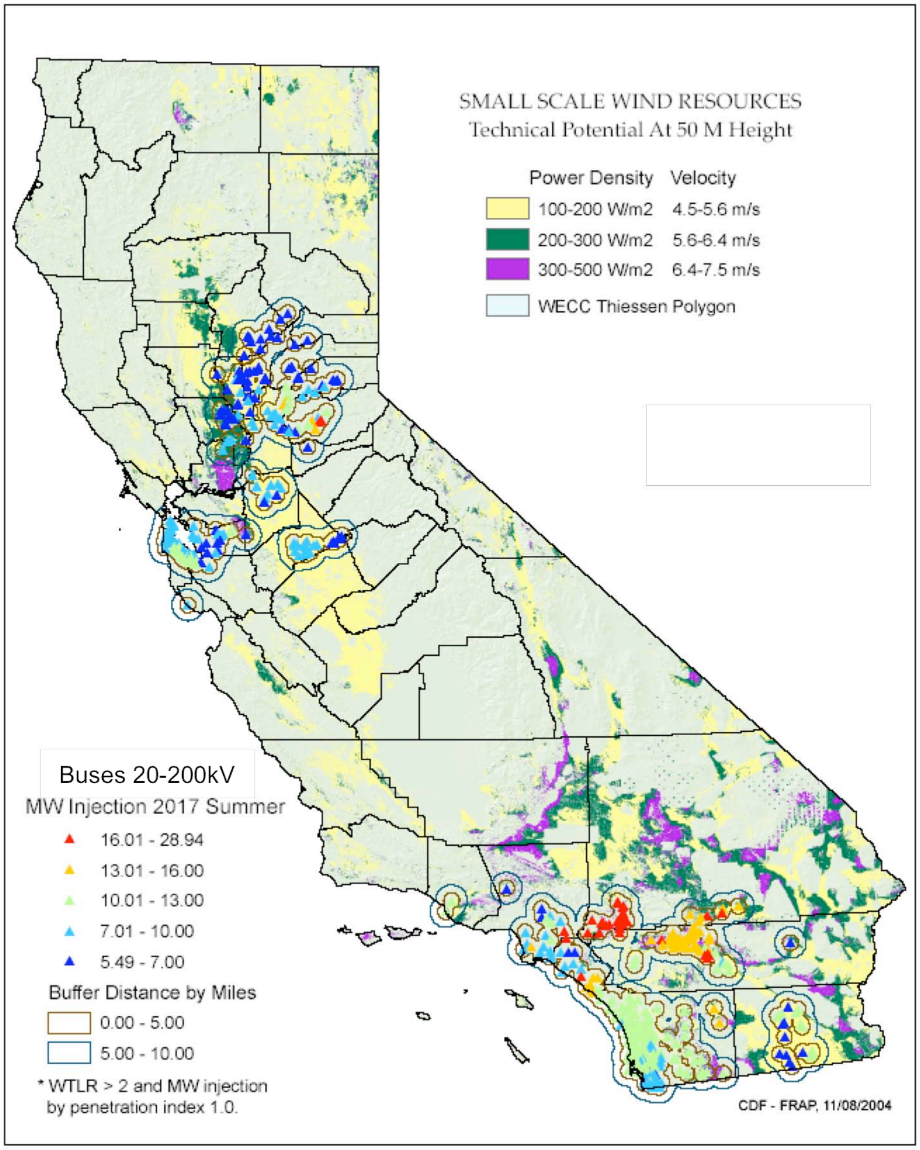
Table 13. 2017 and Beyond SVA Wind Results

Site	MW Installed	ETWC (MW)	Impact Ratio	Rating	Transmission Upgrade Cost
Solano (PG&E plan)	100	60	--	--	$140 M
LA/Kern (SCE plan)	2376	1426	--	--	$843 M
San Bernardino	280	168	-5.3	Excellent	$34 M
San Diego – Los Coches	100	60	-1.6	Excellent	$55 M
San Diego – Miguel (SDG&E plan)	400	240	--	--	$51 M

LWS Hotspot Analysis

Distribution level "hotspots" (20-200kV lines) were initially identified throughout the state. Twenty-one counties with significant low-voltage transmission congestion alleviation benefits were identified by overlaying 50m wind resources over the distribution level "hotspots" (Figure 13). All windy acres were identified by county (Table 14). This process resulted in between 13-26 MW of additional DG wind generation additions to the grid, depending upon the kilowatt-per-acre land coverage ratio. This amount did not significantly change the transmission study but was included in the final analysis.

Figure 13. Overlay of "Hotspots" with LWS Resources at 50 Meters.



Source: California Energy Commission

Table 14. Hotspot LWS Potential by County - 10 Mile Buffer

County	Wind Class Range (W/m^2)	sqmi in 10mi buffer	Total windy acres in county	MW by county (10kW per 0.5 acre)	MW by county (10 kW per 1 acre)
Yolo	200-400	0.4129	264.20	5.28	2.64
Riverside	200-800	0.3985	254.99	5.10	2.55
San Diego	200-800	0.3334	213.32	4.27	2.13
San Bernardino	200-800	0.3309	211.76	4.24	2.12
Solano	200-400	0.1645	105.26	2.11	1.05
Sutter	200-500	0.0962	61.57	1.23	0.62
Alameda	200-800	0.0478	30.57	0.61	0.31
San Joaquin	200-600	0.0454	29.06	0.58	0.29
Los Angeles	200-800	0.0435	27.84	0.56	0.28
Butte	200-400	0.0000	24.97	0.50	0.25
Ventura	200-800	0.0369	23.63	0.47	0.24
Sacramento	200-300	0.0299	19.13	0.38	0.19
Imperial	200-800	0.0248	15.84	0.32	0.16
Orange	200-800	0.0240	15.37	0.31	0.15
Contra Costa	200-800	0.0184	11.76	0.24	0.12
San Mateo	200-600	0.0030	1.90	0.04	0.02
Placer	200-800	0.0010	0.63	0.01	0.01
San Francisco	200-400	0.0007	0.43	0.01	0.00
Plumas	200-500	0.0006	0.40	0.01	0.00
Sierra	200-400	0.0004	0.24	0.00	0.00
Marin	200-500	0.0001	0.09	0.00	0.00
Total State		**2**	**1313**	**26**	**13**

Source: California Energy Commission

LWS Targeted Analysis

The third category was exploration of separate low wind speed developments neither close to nor integrated into high wind development sites. The regions considered in this analysis are shown in Figures 14 through 22.

Table 15 illustrates this low wind speed development potential by county. The second and third columns show the low wind speed potential for average wind power densities fewer than 200 W/m^2 and 300 W/m^2, respectively. For this analysis, the 300 W/m^2 data were further reduced as follows: Alameda, Imperial, Kern, Los Angeles, Riverside, San Bernardino and San Diego Counties were eliminated since they have large penetrations of high and low wind potential. Solano County was included since there is a large low wind potential located in the middle of the county. Contra Costa County was included since it has a large wind potential in the southeast corner of the county. The other counties were eliminated since they are either located far away from transmission or are too small to consider. A 35 percent summer coincident peak capacity factor was applied for the remaining counties, yielding summer peak capacity values found in the right column of Table 15.

Table 15. Connected and Summer Peak Capacity for Projected Low Wind Development Sites

County	Low Wind MW for wind > 200/m^2	Low Wind MW for wind > 300/m^2	Low Wind Summer Peak MW
Alameda	279	183	0
Contra Costa	205	79	28
Imperial	2,974	306	0
Inyo	2,006	326	0
Kern	4,992	2,028	0
Lassen	766	104	0
Los Angeles	2,549	1,334	0
Merced	148	15	0
Mono	719	151	0
Monterey	408	5	0
Orange	119	22	0
Riverside	4,626	1,065	0
San Bernardino	16,682	2,989	0
San Diego	1,628	642	0
San Joaquin	133	17	0
Siskiyou	415	119	41
Solano	2,062	464	160
Ventura	551	143	50
Yolo	487	7	3
Total	**41,748**	**9,999**	**282**

Source: California Energy Commission

The 812 MW of connected low wind potential in the five counties correspond to 282 MW under summer peak load conditions. The 282 MW studied in this report represent only 8 percent of the total low wind potential. The majority of the summer peak low wind development would be located near the high wind sites and would therefore be incorporated into the full integration of wind site development.

The first simulation was a 2010 Summer Peak Base Case. These results determined if low wind generation upgrades provide a positive or negative impact to the system. The entire area of California was modeled for the base case, as well as the wind penetration cases. The base case contingency analysis produced a cumulative AMWCO (Aggregated Megawatt Contingency Overload) value of 17,729 MW.

The first simulation included the full 8 percent of the total low wind potential. A total of 282 MW of low wind generation was installed. Table 16 lists the counties, bus IDs, and MWs installed.

Table 16: Low Speed Wind Projected by County, Bus ID, and Installed MW

County	Bus ID	Installed MW
Contra Costa	33170	28 MW
Siskiyou	45069	41 MW
Solano	32088	60 MW
Solano	32112	50 MW
Solano	32098	50 MW
Ventura	24098	50 MW
Yolo	31253	3 MW
Total		**282 MW**

The next simulation was modeled without low wind generation in Solano. Visual inspection revealed that the inclusion of Solano resulted in a reduced benefit ratio. A new case was modeled without the Solano wind generation, thus reducing the installed MW to 122 MW of low wind generation. Without low wind generation at Solano, the benefit ratio was doubled to -0.6 MW. The contingency analysis AMWCO value was 17,656 MW, which has an impact value of -73. However, since that value is divided by a much smaller installed MW value, the benefit ratio is naturally higher. Table 17 lists a summary of the results from the low speed wind simulations.

Table 17: Summary of Low Speed Wind Results

	2010 Base Case	**2010 Case with 282 MW of Low Wind**	**2010 Case with 122 MW of Low Wind**
Contingencies:	373	377	373
AMWCO:	17,729 MW	17,648 MW	17,656 MW
Impact Value:	- -	- 81 MW	- 73 MW
Benefit Ratio:	- -	- 0.3 MW	- 0.6 MW

Even though the benefit ratio with the Solano County low speed wind resource is small, this site is located close to urban areas and should still be considered as a potential site for expanded development.

Even though many of the other low speed wind sites studied under the scenarios were not necessarily located near transmission hotspots or congestion areas, these sites provide:

- Alternative renewable energy development locations.
- Basic neutrality on transmission impact.
- Economically viable sites for future development.

Figure 14. California Statewide Low Speed Wind Resource Areas.

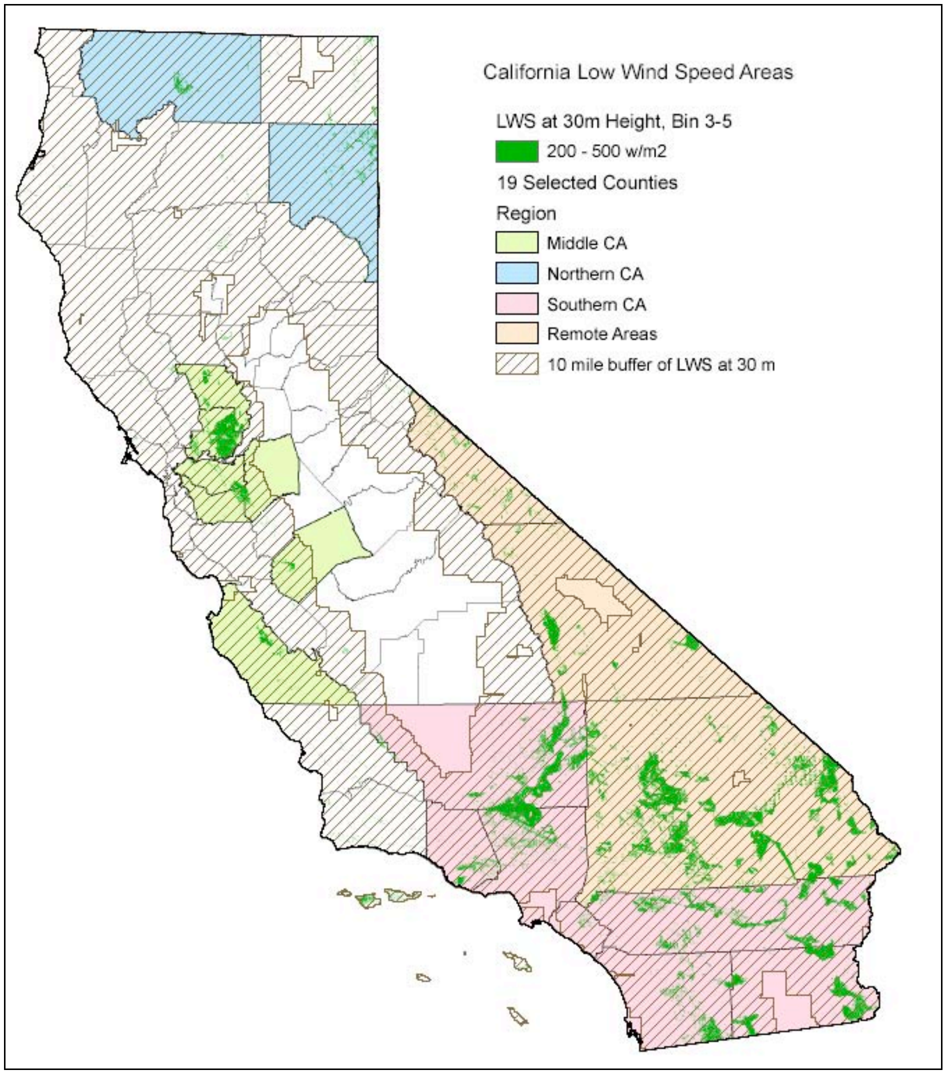


Figure 15. California Low Wind Speed Areas with Bus Overlays

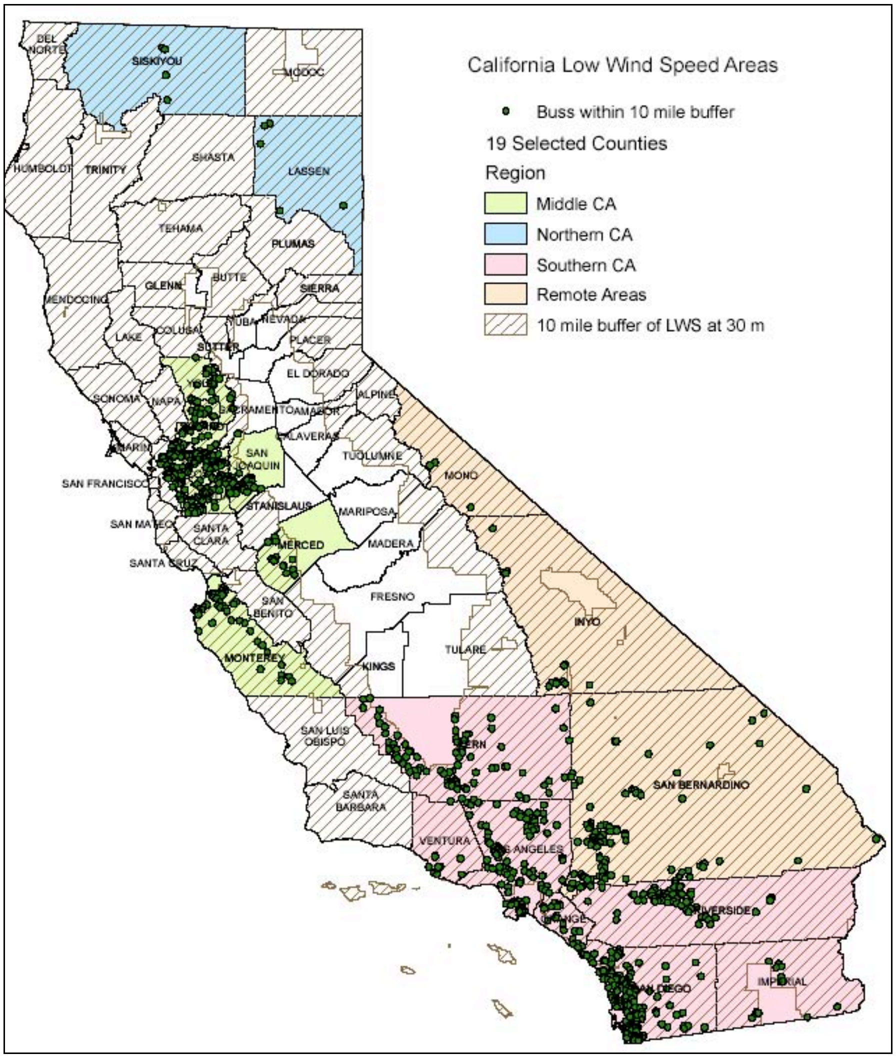


Figure 16. California Low Wind Speed Areas - Alameda and San Joaquin

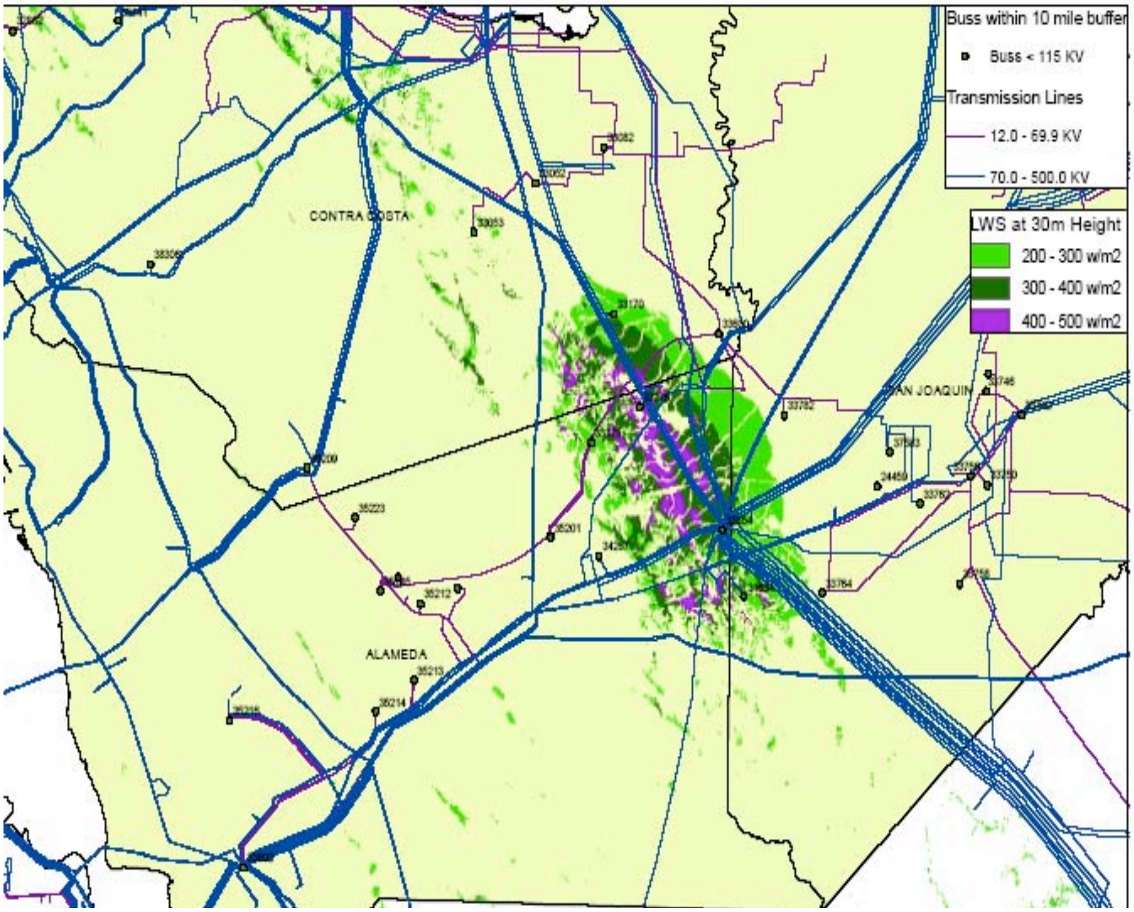


Figure 17. California Low Wind Speed Areas - Imperial

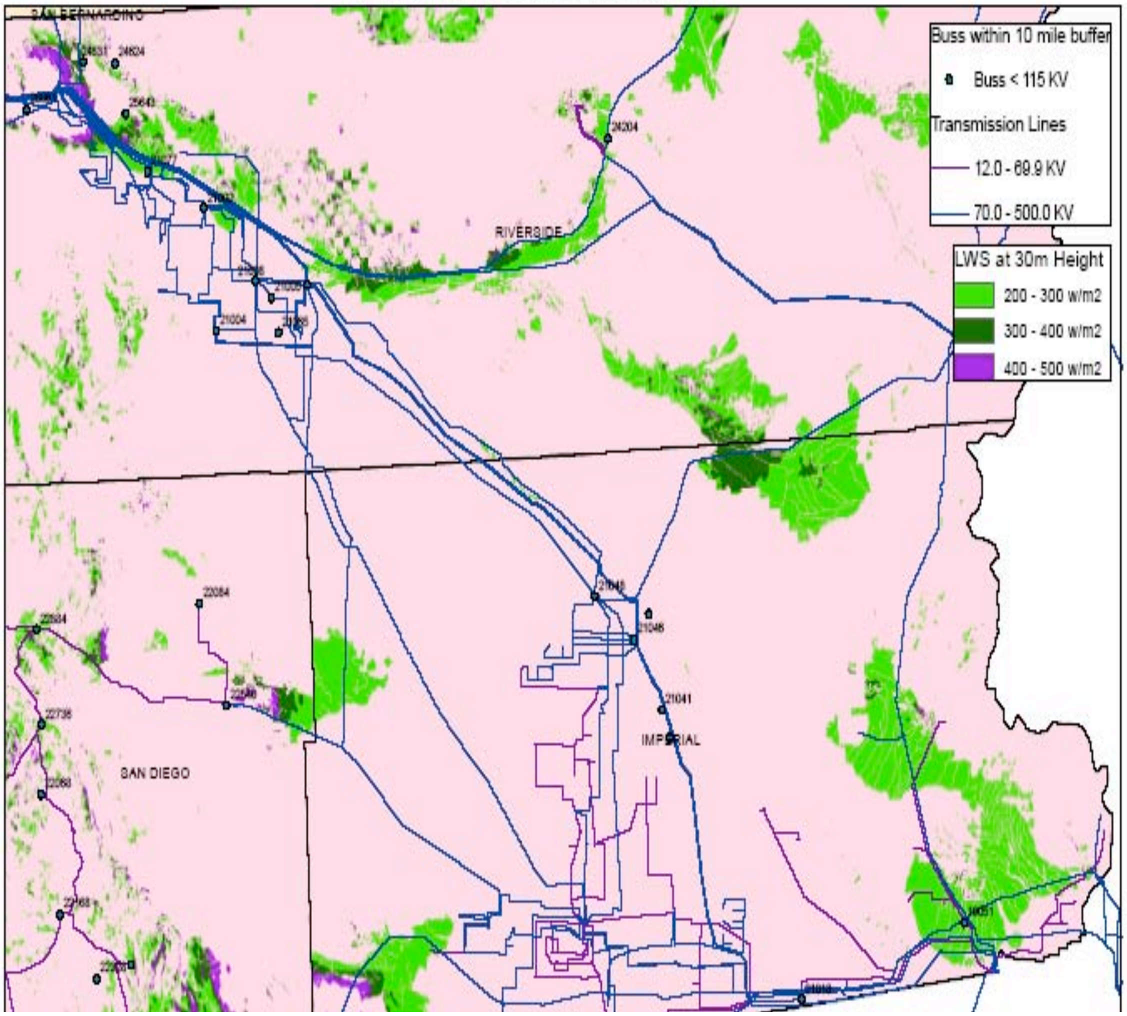


Figure 18. California Low Wind Speed Areas - Lassen

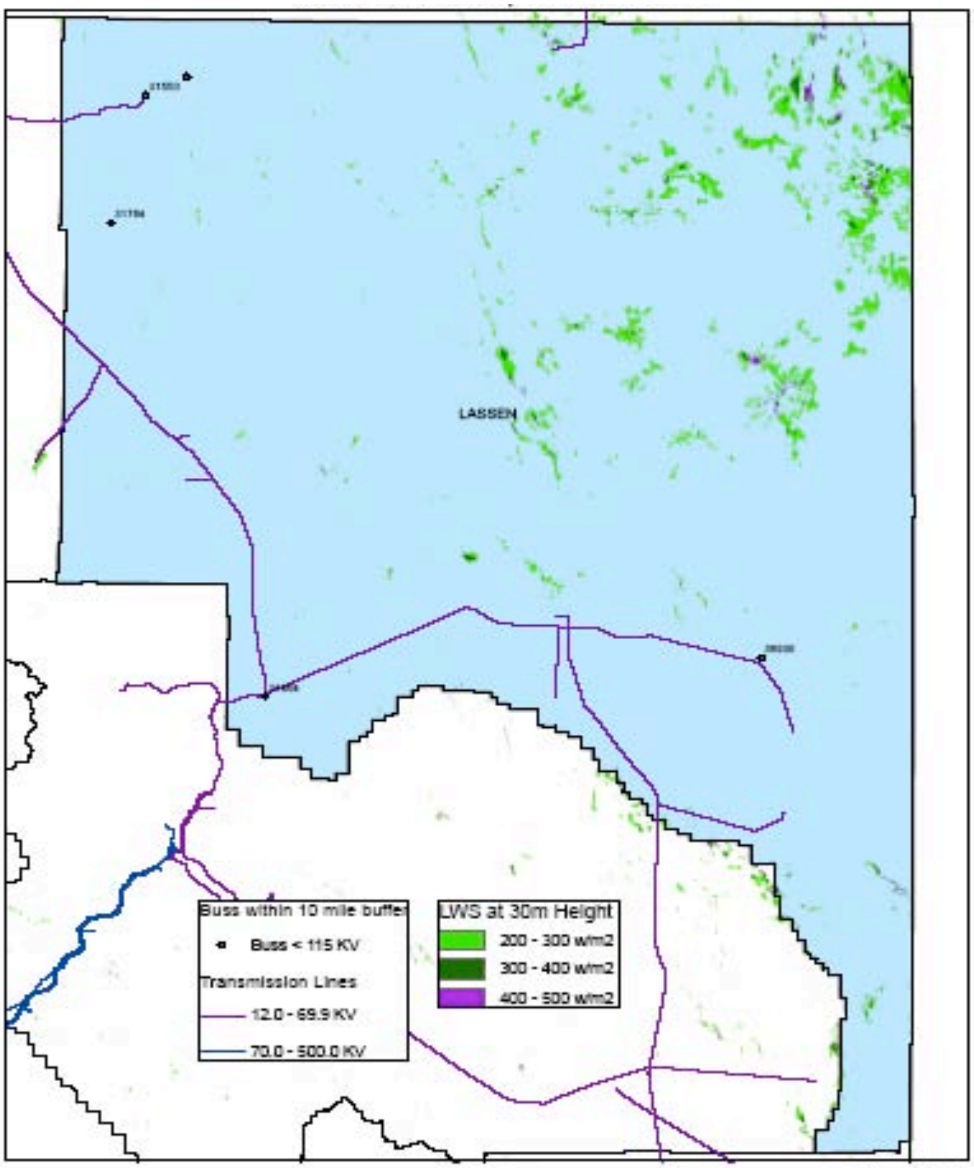


Figure 19. California Low Wind Speed Areas - San Diego

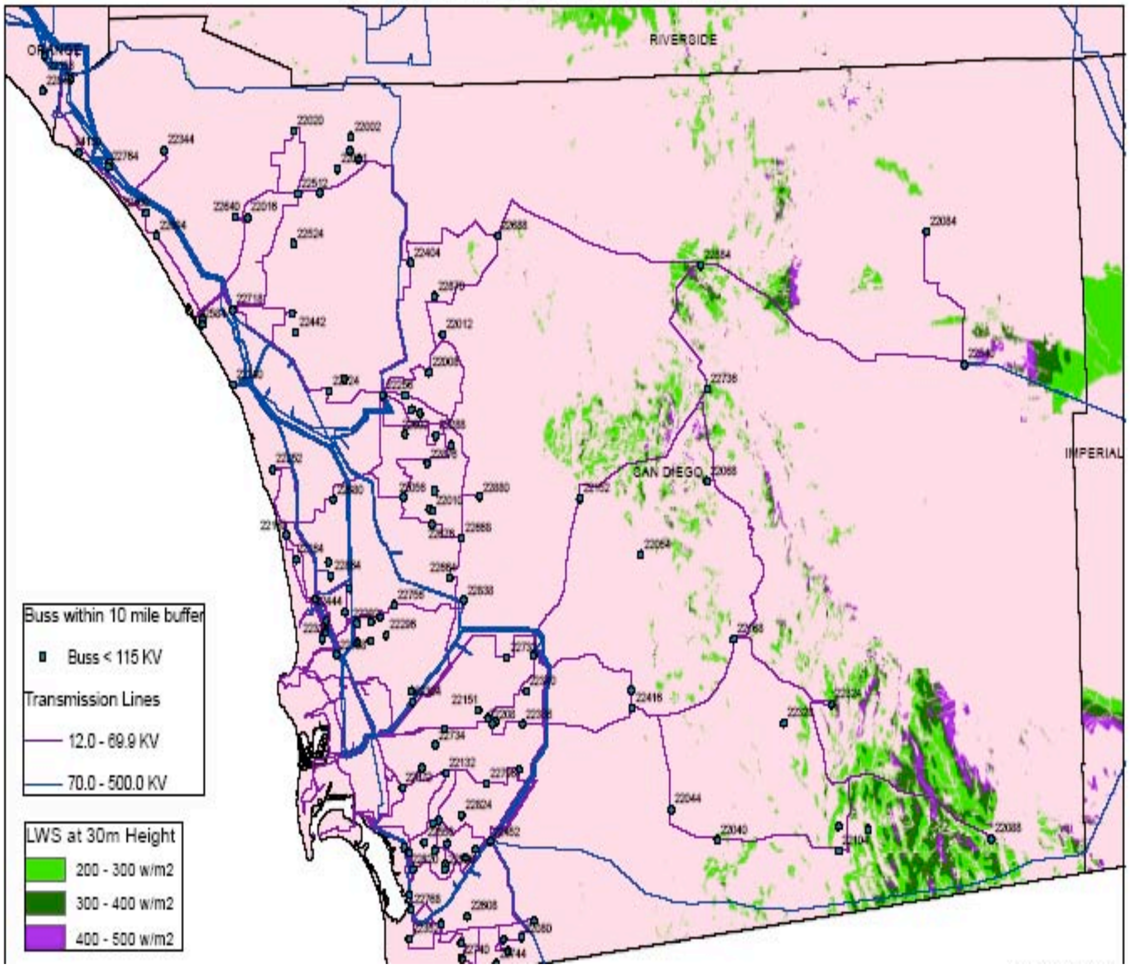


Figure 20. California Low Wind Speed Areas - Siskiyou

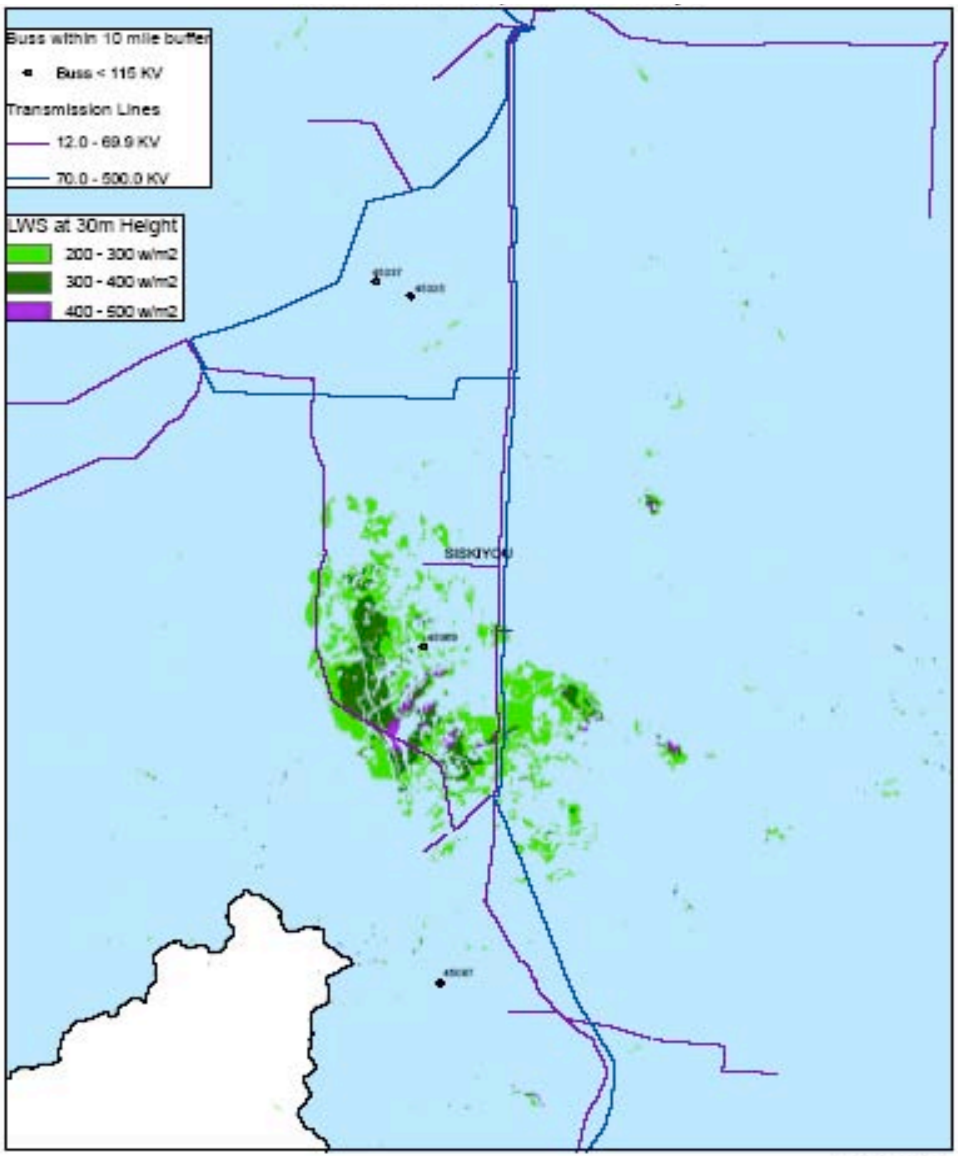


Figure 21. California Low Wind Speed Areas - Solano

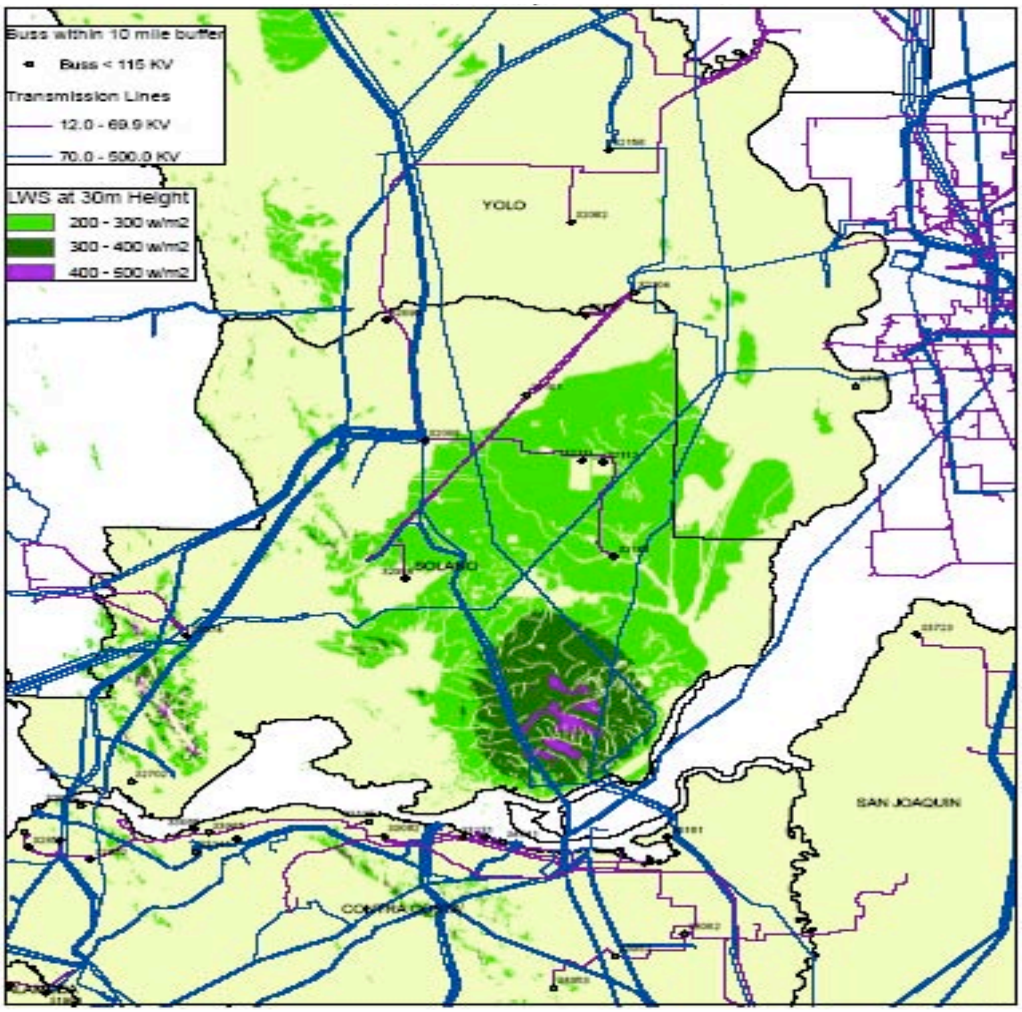
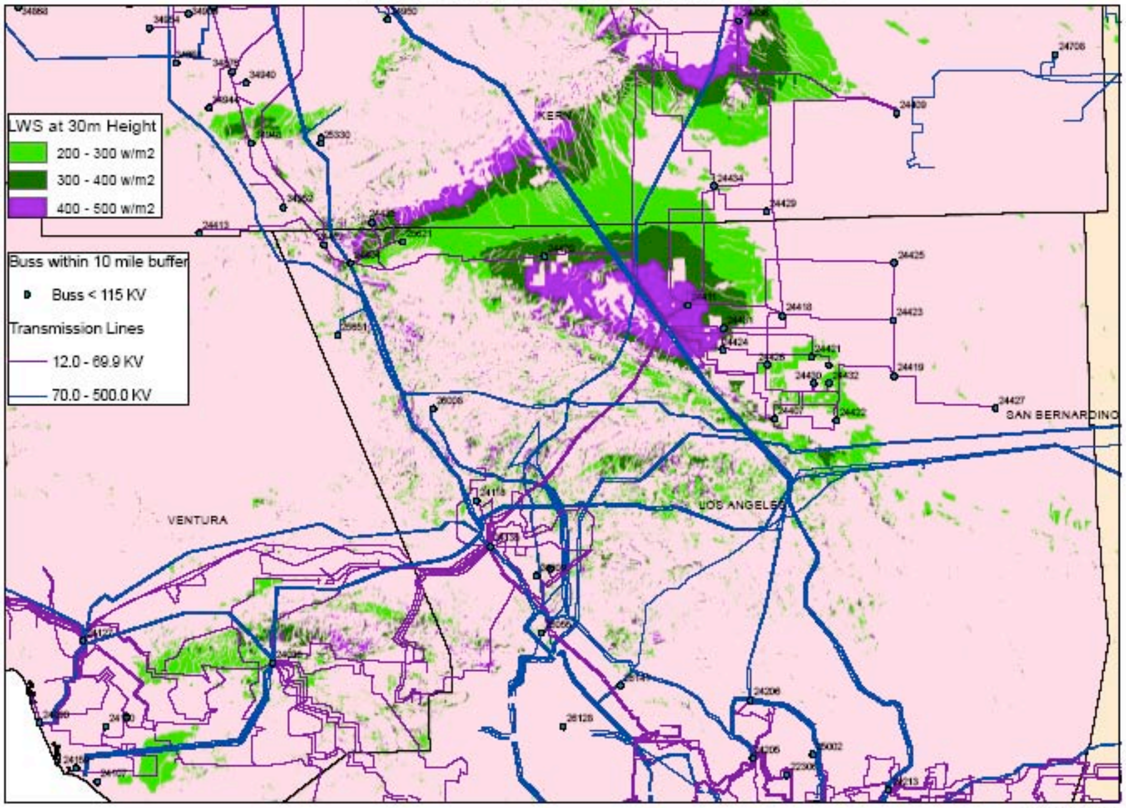


Figure 22. California Low Wind Speed Areas - Ventura and Los Angeles



Barriers to Development of Wind Energy Generation

Barriers to development of wind-energy projects include: public perception issues, public policy, economic uncertainty, and technical limitations. Improvements in generator and transmission designs have greatly reduced concerns about mechanical noise in modern wind turbines, and aerodynamic improvements in blade design have also reduced the noise impacts of wind turbines.

Despite impressive growth throughout the late 1990s, significant challenges remain for the wind industry. One of the most significant challenges is to provide cost-effective, reliable and dispatchable electricity using an intermittent resource. Resolving these issues will require new technologies, tools, a market infrastructure, policies, and a resource support base.

Technical Barriers

Wind turbine technology has significantly evolved since the 1980s. Evolving from a “grass roots” effort to a multi-billion dollar world-wide industry, wind turbines have become a highly complex and sophisticated technology. New designs and high-tech power electronics have increased overall performance while efficient manufacturing processes have steadily decreased system costs. Despite these tremendous strides, technical barriers against increasing market penetration remain. Some of these barriers include the inability to accurately forecast wind generation, the inability to quickly and accurately analyze wind resource potential, lack of low-wind speed technology, and the lack of storage capability.

The inability to accurately forecast wind generation remains a major technological barrier against increasing market penetration. Windpower’s most frequently-cited drawback is its lack of dispatchability. Intermittent systems are difficult to manage and integrate and have a de-rated capacity value from an operational perspective. Wind resources are by nature intermittent and, for the most part, do not conform to high load/demand schedules.

Resources are being invested to develop reliable wind energy forecasting capability. The goal is to provide operators, utilities, and electricity scheduling coordinators with a predictive tool to efficiently integrate and dispatch wind resources. Advanced meteorological forecasting models, atmospheric and fluid modeling codes, as well as statistical methods are being investigated to provide forecasting capability to meet near real-time and day-ahead operational needs.

Another way to address the intermittency issue is to back up the wind generator with some storage capability. Based on studies in California, wind resources consistently met generation demands 80-85 percent of the time. The unmet times occurred when the wind was not blowing. Having the capability to store energy for even short periods to match system demand profiles would significantly increase the “controllability” and value of wind resources.

The inability to quickly and accurately measure and assess wind resource potential is a technological barrier to rapid market development. Until recently, wind resource maps required a significant amount of time and expertise by meteorologists to create and interpret. Experienced meteorological consultants used these maps as guides to site turbines and locate projects. With advances in GIS technology and computing resources and atmospheric modeling codes, the capability exists to easily identify wind development sites and produce high-resolution resource maps. Modern codes may not alleviate the needs for micro-siting or the expertise of meteorological consultants, but they do provide resource tools to assist in communicating wind potential and more cost-effectively exploring new site options and tradeoffs. These resources help mitigate some of the uncertainties and risks of project development.

New wind resource measurement capability is also needed to penetrate untapped resources (new sites, higher elevation). Traditional cup-anemometer and met towers are no longer sufficient in acquiring the type of data needed for modern wind turbines. Traditional towers provide limited information at a point and require a minimum of one year sampling. Traditional cup devices are highly inaccurate and contain moving parts that are easily damaged. The height of modern turbines also poses a challenge for erecting tall met towers, adding to the cost of site exploration. New capability is being developed using devices such as sonic detectors, sodar (sonic detection and ranging) and even lidar (light detection and ranging) to sample a volume of data at various elevations versus a specific point. Although these devices are not new technologies, their use is new to the wind industry. The advantage is that these techniques provide data difficult to obtain using traditional means; the disadvantage is that they are more costly compared with traditional means, often by an order of magnitude.

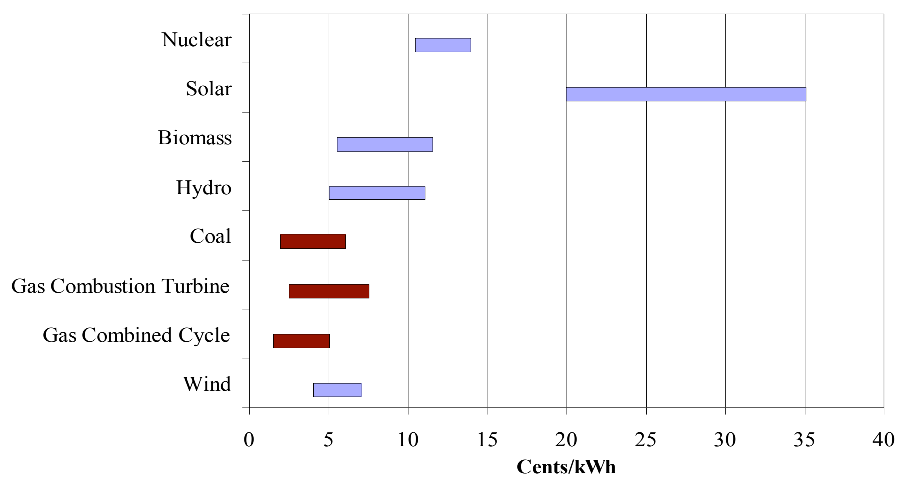
By including and tapping low wind resource areas in the U.S., 12 times more land resources become available to develop wind turbine facilities. Based on the new wind resource maps, significant potential exists in low-wind resource areas (Class 3 winds). These areas were originally overlooked as being uneconomical to develop, with insufficient winds to drive existing turbines. Specifically for California, tapping into low-wind resources would provide a means to locate renewable generation closer to demand centers, offsetting T&D investments, reducing emissions and pollution in the Central Valley and encouraging DG in areas with low to moderate winds. New turbine technologies need to be developed to harness available winds in these resource areas. New technologies could include new, taller horizontal-axis turbines with larger rotor swept areas, or smaller more building-integrated designs.

Economic Barriers

Wind turbines represent a larger up-front investment than conventional power facilities, but growing economy-of-scale and lack of emissions, plus the absence of fuel dependence or cost, make wind an increasingly attractive energy solution in today's economic and political climate. At the utility scale, the cost of electricity produced by a wind turbine can rival those of a conventional power plant, at \$0.04 to \$0.07/kWh. The federal wind-energy production tax credit (PTC) provides \$0.018/kWh for electricity generated during the first 10 years of operation of a new wind plant. Such government incentives and public support have spurred rapid growth in the wind power industry. The current PTC expires at the end of 2003.

Figure 23 shows that, compared with other renewable resources, wind ranks as one of the least expensive technologies.

Figure 23. Levelized COE From Various Energy Generating Sources



Source: California Energy Commission

Large-scale wind turbine capital costs have decreased significantly since the 1980s, from more than \$2500/kW to just under \$1000/kW in the late 1990s. This in turn has reduced the levelized cost of energy (LCOE) from 15-20 cents/kWh in the 1980s to 4-7 cents/kWh in the 1990s, without special price considerations. It is forecasted that LCOE must be under 3.5 cents per kWh, unsubsidized, for wind power to be economic.

Despite these significant improvements, wind energy is still not considered "valuable" in the electricity market. The industry has long maintained control over generation and assigns a value to control and reliability. The "value" of electricity varies, depending upon its reliability, controllability, and when and where it is generated. Intermittent resources, such as wind-generated electricity, are deemed less valuable because they are generated when the resource is available, regardless of scheduling requirements. Under the market management structure, wind generation units must also be “backed” by dispatchable generating units to maintain system reliability. This decreases the capacity value of wind units and increases the overall operating costs to the grid (transmission, regulation & load following). When compared with conventional, dispatchable generating resources, wind energy cannot effectively compete in this structure.

The following are existing economic barriers to consider:

- Market competition with other generation technologies.
- Intermittency, reducing overall value of wind-generated electricity on the grid.
- Intermittency, making scheduling, regulation and control difficult.
- Heavy imbalance and uninstructed costs are levied against wind operators making the whole system non-cost competitive.
- High capital costs, as compared with base load systems.
- Lack of a United States manufacturing base, so that manufacturing cost reductions are not realized.
- Lengthy and expensive permitting costs.

With the recently adopted RPS in California and a national RPS under consideration, determining the real value of wind energy is becoming more important. Wind resource intermittency creates more than just technological problems, and requires creation of a market infrastructure that could accommodate the uniqueness of this resource. System advances have continued to reduce the cost of energy. However, for the wind industry to truly compete without special pricing conditions, a considerable market redesign and renewable management structure is needed.

Environmental Barriers

Many birds and bats are killed annually from collisions with wind turbines; however, the number of collisions differs between wind resource areas and is dependent on the level of bird and bat activity in a given area. There has been some concern about the visual impact of wind turbines, but this can be minimized through design. Noise was an issue with some early wind turbine designs, but it has been largely eliminated through improved engineering and appropriate use of setbacks from nearby residences. Aerodynamic noise has been reduced through modifications to blade geometry and orientation. A small amount of noise is generated by mechanical components of the turbine, but is not noticable at a moderate distance from the turbine. Erosion can be a concern in certain habitats like deserts, where a hard-packed soil surface must be disturbed to install wind turbines, but this can be prevented through proper installation and landscaping techniques.

Although wind does not produce direct emissions, indirect emissions do exist and may have environmental consequences if not properly addressed. These indirect emissions include acoustic emission, visual pollution, manufacturing byproducts, land erosion, and bird and bat kills. Noise and visual impact remain an important consideration for siting of wind facilities close to populated areas. On new turbines, better blade aerodynamics and lower tip speeds are helping to reduce the low frequency turbine noise. Larger and slower turning turbines are also improving the aesthetic appeal of turbines by reducing the visual “clutter and “stress” created by the more numerous smaller turbine technologies.

Avian collisions with wind turbines occur at all California wind farms, although the number of collisions differs between areas. Collisions are particularly high at the Altamont Pass Wind Resource Area due to the combination of approximately 5000 operating turbines and a high concentration of raptors year-round. The rate of bird use and collision differs in other wind resource areas in California with Solano County having a high rate of collision and San Gorgonio and Tehachapi Pass having lower rates. More recently, bat fatalities have become an issue at some wind farms including the Solano County WRA, where surveys for bats have been conducted. The extent of bat fatalities at other California wind resource areas has not been investigated and is therefore uncertain. The effect of increases in turbine size, height, and rotor swept area on the frequency of collisions has not been tested and is not known. Flight heights of birds in the Altamont suggest that blade reaches above 29 meters from the ground would avoid most bird flight zones and may lower collision frequency. However, the number of collisions are very high at Solano WRA where larger turbines are installed. This demonstrates the site-specific nature of bird behavior and collision risk. Post construction monitoring is the only way to determine how new technology affects bird and bat fatality rates.

Wind turbines should be sited in areas that reduce impacts on birds. Mitigation measures should be developed for all wind resource areas and applied to existing and new development. Voluntary guidelines for surveys, permit requirements, and mitigation measures exist but are not consistently implemented by industry or local agencies.

A lesser known source of indirect pollution comes from the wind turbine manufacturing industry. Although insignificant compared with pollutants produced by fossil-fueled facilities, the wind industry does have responsibility for waste byproducts resulting from composite and metal manufacturing. As the wind turbine industry continues to grow in the U.S., the treatment and impact of these byproducts need to be considered with new manufacturing facilities.

Ultimately, growth in wind power technology relies not on technology alone but also on policies that govern its operation and development. Technological needs and governing policies must reinforce one another to meet the challenges of this changing industry.

Institutional Barriers

The future of wind industry expansion faces numerous institutional and policy barriers. In addition to high initial capital investment costs, siting and permitting issues (local and regional), and lack of transmission and interconnections, the industry is also at odds with a traditionally conservative utility management culture and market infrastructure.

As an intermittent resource, wind generated electricity to this day is de-rated by the utilities and operators. Due partly to the lack of control and unpredictability of the resource and partly due to the lack of tools to effectively integrate and manage the resource, 1,700 MW of wind capacity and over 3,000 GWh of wind generation are often viewed as system nuisances. New wind resource maps and forecasting capability are emerging as tools to help better identify, site and plan wind resources; however, the mindset of "control and predictability" of wind resources may never be a reality.

In 2003, the California Independent System Operator (CA ISO) implemented the Participating Intermittent Renewable Program (PIRP), which creates a market vehicle for wind generators to compete in the electricity market. A special allowance is made on penalties for participating projects utilizing a standardized forecast for wind generation. The method seemingly provides a benefit by allowing existing wind projects to compete. Though an innovative approach using state-of-the-art forecasting methods, the results remain to be seen as more projects come on line and new technology is implemented. With increasing penetration of wind resources, the cost of forecasting needs to be weighed against accuracies and benefits. Other more cost effective and efficient management means are anticipated. Hybrid technologies such as coupling wind and storage allow for "time-shifting" of resources to high demand periods could maximize the value of wind energy resources. Though designed to stimulate the wind power market in California, program terms such as the PIRP should be regularly re-evaluated in order to accommodate new and changing technologies.

Benefits of Wind Resources

Regarded as environmentally friendly and emission free, wind energy systems provide a way for energy generators to comply with emission and pollution regulation. In 2001, California wind systems generated over 3 billion kWh (3,000 GWh) of electricity, displacing over 7.5 tons of nitrogen oxides (NO_x), 2 million tons of carbon dioxide (CO_2) and well over 15 tons of sulfur dioxide (SO_2) that would otherwise have been emitted from natural gas-fired power plants. Every new MWh of wind-generated electricity displaces approximately 5 pounds of NO_x, 1,300 pounds of CO_2 and 0.01 pounds of SO_2 from these plants.

From a market perspective, wind energy has been the most significant contributor to the green market, offering viable options in electricity generation resources to communities. Wind projects have also been instrumental in revitalizing the economies of many rural communities across the country by offering some near-term and long lasting economic benefits. In west Texas, for example, lease payments from wind turbines have replaced declining payments from depleted oil wells.[1] Throughout the country, local property tax revenue has increased, approximately $1M/year for every 100MW of installed capacity on the property.

Through land lease revenue or royalty payments, wind projects provide farmers and other landowners an additional stream of steady income. In California, the majority of land lease agreements for wind facilities are with landowners, who are typically not farmers. Although leasing arrangements vary widely, landowners in California on average earn approximately 5 percent of the gross revenue from the wind facility, 2-3 percent higher than similar agreements in the Mid-west. This translates to approximately $4,500/MW per year. Additionally, landowners can continue to lease land to farmers for growing crops and tending livestock. Although wind facilities extend over large geographical areas, their actual "footprints" cover only a very small portion of the land, approximately 5 percent of the area, unlike their fossil-fueled generating counterparts. With the majority of the land still available for farmers to continue earning a living, wind development projects provide complementary benefits to both the environmental and economic well being of many communities.

It is estimated that during construction of a wind plant, one to two local jobs are created for every MW of installed capacity. Though wind construction crews are very specialized, local construction crews provide foundation, cement, crane and tower erection and electrical support. For a new 100MW facility, typically a five to six-person crew is retained and/or locally trained to maintain, support and service the wind plant after construction. With a new wind facility nearby, local businesses and restaurants also benefit from the temporary influx of workers and tourists to the area.

Over the past few years, the wind industry trend has been to increase the size, efficiency and reliability of wind turbines, making their deployment more cost effective. As a result, wind power now ranks among the most appealing options for new generation facilities. Technology enhancements are also improving the reliability and performance of these systems and optimizing the uniqueness of this resource.

[1] http://www.awea.org/pubs/documents/FAQ2002%20-%20web.PDF

Summary

With enactment of the California RPS, electricity retailers are facing the challenge of accommodating and integrating significant renewable resources into their system mixes. A significant renewable resource base exists within California. Huge untapped high speed and low speed wind potential remains to be developed. In addition, significant environmental and other non-energy benefits cannot be realized without an infrastructure that can accommodate the intermittent nature of wind generation resources.

Though the Strategic Value Analysis (SVA) effort, the Energy Commission's PIER Renewables Research and Development Program is paving a strategic pathway for the growth and integration of future renewable generation to meet aggressive RPS goals. The effort provides not only a vision for development but a methodology by which renewable resources can be assessed for their energy and non-energy benefits. The effort uniquely combines renewable resource assessments, state-of-the-art power flow simulation analysis, related transmission modeling, and assessment of distributed generation potential for wind resources. SVA findings directly address the magnitude and timeframe for transmission and distribution upgrades as well as a set of priorities and upgrade locations.

Appendix A

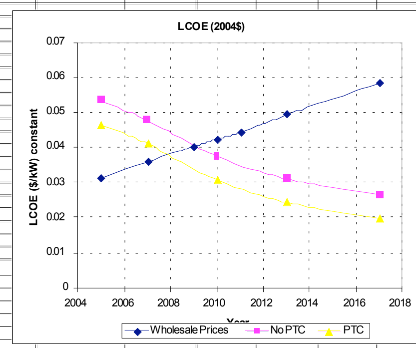
Economic Model Calculation Details (base case 2005)

	A	B	C	D	E	F	G	H
1	Wind Power Plant:	Revenue	Requirements	Economic	Model			
2								
3	This simplified model computes both the current $ and constant $ level annual cost for a wind power plant.							
4	The spreadsheet cells highlighted in green are input cells:		Input Cell					
5	Principal results are highlighted in blue:		Result					
6	This example assumes a 20 year economic life with no salvage value and gives cash flows for each year.							
7								
8	(2004 $)							
9	BASIC ASSUMPTIONS							
10								
11	Capital Costs	Yr 2005		Yr 2005	Yr 2007	Yr 2010	Yr 2013	Yr 2017
12		($)	($/kW)	($/kW)	($/kW)	($/kW)	($/kW)	($/kW)
13	Total Wind Turbine Equipment	31,944,857	638.9	638.9	575.0	479.2	447.2	415.3
14	Rotor Assembly	10,222,354	204.4	204.4	184.0	153.3	143.1	132.9
15	Tower	8,263,070	165.3	165.3	148.7	123.9	115.7	107.4
16	Wind Turbine/Generator	5,451,922	109.0	109.0	98.1	81.8	76.3	70.9
17	Electrical/Controls/Instrumentation	8,007,511	160.2	160.2	144.1	120.1	112.1	104.1
18	Transportation and Freight	2,129,657	42.6	42.6	38.3	31.9	29.8	27.7
19	Balance of Plant / EPC	9,498,271	190.0	190.0	171.0	142.5	133.0	123.5
20	Engineering	212,966	4.3	4.3	3.8	3.2	3.0	2.8
21	Foundations	1,959,285	39.2	39.2	35.3	29.4	27.4	25.5
22	Civil (roads, grading, fences)	638,897	12.8	12.8	11.5	9.6	8.9	8.3
23	Power Collection System	2,598,182	52.0	52.0	46.8	39.0	36.4	33.8
24	SCADA and Communications	212,966	4.3	4.3	3.8	3.2	3.0	2.8
25	Installation and Commissioning	1,788,912	35.8	35.8	32.2	26.8	25.0	23.3
26	Substation, Metering, Interconnection	1,277,794	25.6	25.6	23.0	19.2	17.9	16.6
27	O&M Facility, Met Towers, Sensors	383,338	7.7	7.7	6.9	5.8	5.4	5.0
28	Construction Management	383,338	7.7	7.7	6.9	5.8	5.4	5.0
29	Owner Costs	7,411,207	148.2	148.2	133.4	111.2	103.8	96.3
30	**Total Capital Costs**	**50,983,991**	**1,020**	**1,020**	**918**	**765**	**714**	**663**
31								
32	Net Plant Capacity (kW)	50,000		Net Plant Capacity: Size of plant based on net power output to grid				
33								
34		Yr 2005		Yr 2005	Yr 2007	Yr 2010	Yr 2013	Yr 2017
35	Capacity Factor (%)	37.0		37	38	40	42	43
36				Capacity Factor: Annual fraction that rated capacity is available from plant				
37	Transmission line voltage							
38	Transmission cost ($/mile)	$ -						
39	Miles							
40	Substation MVA							
41	Substation cost ($/MVA)							
42	Total transmission cost							
43								
44	EXPENSES	Yr 2010		Yr 2005	Yr 2007	Yr 2010	Yr 2013	Yr 2017
45	Fuel Cost ($/t)	0		0	0	0	0	0
46	Labor Cost ($/kWh)	0.010		0.010	0.009	0.006	0.005	0.003
47	Maintenance Cost ($/kWh)	0.007		0.007	0.006	0.005	0.003	0.003
48	Insurance/Property Tax ($/kWh)	0.002		0.002	0.002	0.002	0.002	0.002
49	Utilities ($/kWh)	0.001		0.001	0.001	0.001	0.001	0.001
50	Management/Administration ($/kWh)	0.004		0.004	0.004	0.003	0.002	0.001
51	Total Expenses ($/kWh)	0.024		0.024	0.022	0.017	0.013	0.010
52	Total Expenses ($/kW-yr)			77.8	71.3	55.1	42.1	32.4

	A	B	Notes		
53	TAXES				
54	Federal Tax Rate (%)	34.00	Federal Tax Rate: For federal tax calculations		
55	State Tax Rate (%)	6.65	State Tax Rate: For state tax calculations		
56	Production Tax credit ($/kWh)	0.000	Production tax credit = $0.018/kWh	for five years	Section 45 tax Credits HR4520
57	Combined Tax Rate (%)	38.39	Combined Tax Rate: combined federal and state tax rate to which project is subject		
58					
59	INCOME other than energy				
60	Capacity Payment ($/kW-y)	0	Capacity Payment: Payment made from power purchaser if plant can guarantee capacity (depends on contract)		
61	Interest Rate on Debt Reserve (%)	7.00	Interest Rate on Debt Reserve: Interest income earned on reserve account if financing institution requires security deposit		
62					
63	ESCALATION/INFLATION				
64	General Inflation (%)	2.80	General Inflation: Overall inflation rate used to adjust current dollar result to constant dollars.		
65	Escalation-Other (%)	2.80	Escalation-Other: Rate at which other expenses escalate over time		
66					
67	FINANCE				
68	Debt ratio (%)	67.00	Private Developer 67/33 ratio	Debt ratio: Fraction of financing covered by debt borrowing	
69	Equity ratio (%)	33.00	For IOUs need to use 90/10 ratio	Equity ratio: Fraction of financing covered by corporate investment	
70	Interest Rate on Debt (%)	8.40	Interest Rate on Debt: Interest rate applied to debt portion of investment		
71	Life of Loan (y)	20	Life of Loan: Example assumes 20 year economic life		
72	Cost of equity (%)	16.00	Cost of Equity: Rate of return on equity portion of investment		
73	Cost of Money (%)	10.91	Cost of Money: Weighted cost of investment for full investment including both debt and equity		
74	Total Cost of Plant ($)	50,983,991			
75	Total Equity Cost ($)	16,824,717			
76	Total Debt Cost ($)	34,159,274			
77	Capital Recovery Factor (Equity)	0.1687	Capital Recovery Factor: Factor used to compute level annual cost from present worth		
78	Capital Recovery Factor (Debt)	0.1049			
79	Annual Equity Recovery ($/y)	2,837,775	Annual Equity Recovery: Uniform annual revenue required to earn stipulated rate of return on equity		
80	Annual Debt Payment ($/y)	3,583,397	Annual Debt Payment: Uniform annual payment needed to pay off debt		
81	Debt Reserve ($)	3,583,397	Debt Reserve: Funds placed in reserve account as security deposit.		
82	Annual Debt Reserve Interest ($/y)	250,838	Sometimes required by financing institution to ensure debt repayment if plant operation is stopped		
83	Annual Capacity Payment ($/y)	0	for some period, typically up to one year.		
84	Loan Origination Fee (% of total cost of plant)	2			
85					
86	ACRS DEPRECIATION				
87	Year1	0.2000			
88	Year2	0.3200			
89	Year3	0.1920			
90	Year4	0.1152			
91	Year5	0.1152			
92	Year6	0.0576			
93	Total	1.0000			
94	Additional 30% first year depreciation (%)	30			
95	Annual Production (kWh)	162,060,000			
96	Annual Hours	3,241			

Results			
Wind Power Plant			
LCOE ($/kW)		2004 Constant$	
Year	**Wholesale price**	**No PTC**	**PTC**
2005	0.0316	0.0535	0.0468
2007	0.0363	0.0478	0.0411
2009	0.0405	-	-
2010	0.0426	0.0375	0.0307
2011	0.0446	-	-
2013	0.0495	0.0312	0.0245
2017	0.0587	0.0266	0.0199

RESULT, constant $ 0.0535



127	**Constant $ Level Annual Cost (LAC)**	
128	Real Cost of Money	0.0789
129	Capital Recovery Factor (constant)	0.1010
130	Constant $ Level Revenue Requirements	8,670,251
131	**Constant $ LAC of Energy ($/kWh)**	0.053

Endnotes

1. Thresher, R. W., Hock, S. M., Loose, R. R., Goldman, P., "Wind Technology Development: Large and Small Turbines," NREL Report No. TP-440-7224, 1994.

2. http://www.nrel.gov/research/wind/wind_turbines.html

3. Economic assumptions. http://www.energy.ca.gov/reports/2003-11-24 500-03-080F.pdf

4. California Energy Commission, *Electricity Infrastructure Assessment Repo*rt, May 2003, pgs. 15-19

5. American Wind Energy Association, http://www.awea.org/pubs/documents/FAQ2002 percent20-percent20web.PDF